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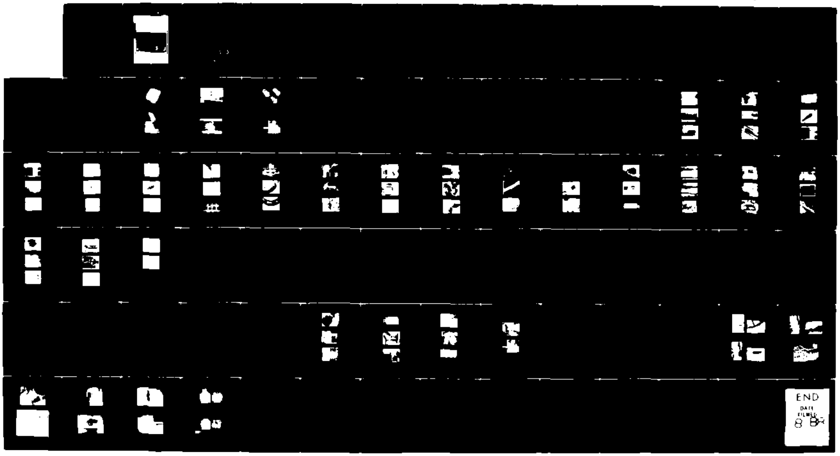

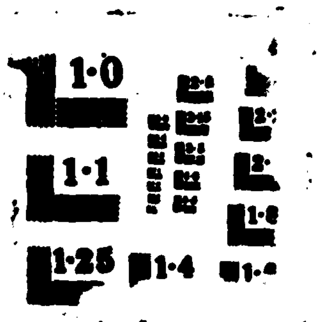
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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Report No.733

WORKSHOP ON AVIONICS CORROSION CONTROL

Papers presented at the 62nd Meeting of the Structures and Materials Panel of AGARD in Høvik, Norway on 16—17 April 1986.

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— Exchanging of scientific and technical information;

— Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;

— Improving the co-operation among member nations in aerospace research and development;

— Providing scientific and technical advice and assistance to the Military Committee in the field of aerospace research and development (with particular regard to its military application);

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PREFACE

The degradation of avionics systems through corrosion has become a costly problem in military aircraft; the high failure rates attributed to corrosion suggest that equipment is not being designed for or tested in environments likely to be encountered on operations.

The Structures and Materials Panel held a Workshop to examine the extent of this problem; the aims were

(a) to make the AGARD community aware of the extent of the problem

(b) to ascertain from designers and materials specialists the state-of-the-art in devising protection schemes applicable to avionics

(c) to encourage further development work on new protection products, procedures and techniques

(d) to determine the prospects for the substitution of non corroding composite materials for metallic materials in avionics

(e) to consider preventive maintenance programmes for corrosion avoidance.

This document contains the keynote and other presentations made to the Workshop.

ABSTRACT

This document contains the keynote and other presentations made at a Workshop held by the Structures and Materials Panel on Avionics Corrosion. The discussion covered the problem's extent, the state of the corrosion-prevention art, the prospects for innovative corrosion avoidance techniques including the substitution of non-metallic for metallic materials and preventive maintenance techniques.

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Ce document contient les documents clefs ainsi que d'autres exposés, présentés au cours de l'Atelier organisé par le Groupe chargé des Structures et des Matériaux, sur la corrosion affectant l'avionique. La discussion a porté sur l'ensemble du problème, sur l'état actuel de la technique concernant la prévention de la corrosion, sur les perspectives en matière de techniques innovatrices permettant d'éviter la corrosion, y compris le remplacement de matériaux métalliques par des matériaux non-métalliques, et les techniques de maintenance préventive.

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AVIONIC CORROSION

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SUMMARY

This paper discusses

The paper will discuss the major causes of corrosion in the Navy's avionic equipment and provides specific examples of corrosion failures. Maintenance and readiness data summaries ~~will be~~ are included to denote further the corrosion problem severity. Corrective measures in design, testing and maintenance ~~will be~~ are reviewed.

INTRODUCTION

In today's sophisticated naval aircraft, the avionic systems represent 30-50% of the cost of the total weapon systems and their performance is critical to the overall mission capability. Consistently however, the reliability of such equipment when it is deployed in fleet service is significantly below that predicted during the design and demonstration phases. There are military specifications, standards and handbooks that describe design characteristics of various components that are to be used in new avionic equipment. Also, there are laboratory tests designed to demonstrate the capability of the assembled equipment to meet prescribed requirements relative to shock, vibration, salt spray, temperature, EMI, and other characteristics that can be quantified and measured. These design and test requirements, however, have not been adequate to preclude the recurring increased failure rates when equipment is operated and maintained in the naval environment.

Investigations conducted during the past ten years have increasingly identified corrosion as a major unforeseen degradation factor for electronics placed in the naval aircraft fleet environment. While fleet conditions are difficult to duplicate in a laboratory, it is possible to minimize equipment susceptibility through enlightened design - once the causal factors are recognized and understood. On-site surveys (1) of front line combat aircraft have concluded that the significant design factors contributing to corrosion are; poor resistance to moisture intrusion, numerous unnecessary matings of dissimilar metals, and fluid conduits within the airframe.

MOISTURE AND FLUID INTRUSION

Avionic equipment, whether internal or external to the aircraft, on the repair bench or in storage can be susceptible to conditions such as changing temperatures and pressures, varying humidity, dust, dirt and industrial pollutants in the atmosphere. In addition the Navy's aircraft carrier environment exposes sensitive electronics to a combination of moisture, acidic deposits from stack gases, jet engine exhaust, and salt spray. The equipment that suffers the most from these environmental effects are those mounted external to the airframe such as; antennas, electronic countermeasure pods, photographic pods and lights. There are many situations where avionic devices are installed behind doors and panels that leak during flights through rainstorms or on low level flights over water. If the integrity of the airframe is less than perfect during rainstorms, fresh water washdowns can be equally hazardous. High pressure washing units deluge the aircraft with tremendous amounts of water in a short time. Two prime examples of susceptibility to this condition are the clamshell doors on helicopters and radomes on fixed wing aircraft. These doors and radomes leak like sieves when the gaskets become worn or damaged. In addition, exhaust fan inlet ducts, ram air cooling ducts, and vapor exhaust ports that are designed without a self-sealing mechanism become excellent access areas for water and mositure intrusion. Helicopters, in particular, are designed with minimal consideration for the operational environment. There are numerous flight scenarios that require cockpit windows and cabin doors to be open. Numerous cases exist where control boxes and communication equipment are mounted aft, or below, the door and window openings, allowing water to enter the equipment. Figure 1 provides an excellent example of the effects of water intrusion. This severely corroded power supply sub-assembly, mounted in the turtle back area behind the cockpit on the A-6 aircraft, was victimized by frequent water intrusion soakings.

The external bulkhead electrical connectors, external wire and cable runs, antennas, control linkages and other such areas where the shell of the fuselage is penetrated can become potential sources for moisture and fluid intrusion. The list of airframe integrity problems relative to water intrusion during flight is extensive.

Besides the water intrusion problems occurring during flight, airframe integrity is compromised also in the maintenance periods. Many additional problems are encountered while aircraft are parked on the flight deck. In general during the majority of their ground time aircraft are opened up or unbuttoned to some degree. The need for canopies to be open during certain maintenance functions produces situations where rain and salt-spray may soak cockpit avionic components. The removal of a waveguide or a doppler or ADF antenna from the aircraft exposes the supporting electrical connectors, harnesses and cables to the environment. The troubleshooting of radars on fighter and attack aircraft may require the radomes to be open for hours on end, continually exposing the

equipment to rain and salt-spray. The same is true during troubleshooting in avionic bays and compartments.

Environmental control systems add another insidious facet to the overall problem of moisture and fluid intrusion. These systems are not operated on a round the clock basis. The avionics are protected while the environmental control system is supplying conditioned air during flight and then are exposed to a completely different and harsher environment during the more extensive time spent on the ground. The equipment becomes particularly prone to water condensation when the aircraft after sitting for long periods of time on a hot carrier deck undergoes rapid changes in temperature at flight altitudes. Moisture condenses on cooled surfaces, during flight, and then is trapped until natural evaporation mechanisms take over during down time.

After moisture or fluids enter an airframe or avionic compartment it may follow a natural conduit directly into a sophisticated piece of avionic equipment. Hydraulic and fuel lines, control surface linkages, oxygen lines, waveguides, structural stringers and electrical wire/cable runs act as natural conduits to moisture and fluids. It is common to find that antenna and radars mounted in the lower fuselage are adversely affected by moisture intrusion which runs down the antenna coaxial cable and/or waveguide that carry the signals to and from the equipment. As these cables and waveguides pass through deck plates and bulkheads, where water is present, they act as conduits carrying the fluid into the connectors attached to the equipment.

THE EFFECTS OF CORROSION ON AVIONIC COMPONENTS

The avionic systems on aircraft are not isolated 'black boxes' sealed against the environment. There are many components, relays, terminal boards, circuit breaker panels, switches, lights, etc. that make up a complete system. In addition, a sophisticated aircraft may contain miles of wire and coaxial cables and hundreds of electrical connectors. Corrosion attack on the various elements that make up the total avionic systems can create numerous problems in relation to reliability and maintainability. Table 1 summarizes the effects of corrosion on avionic components.

Antennas are the most corrosion prone components in the Navy's airborne electronic systems. The problem of antenna corrosion have become more severe in recent years due to the increased number of avionic systems which has created the need for many additional antennas per aircraft. Corrosion of antennas and associated hardware can cause degradation in system performance through shorts, open circuits, signal attenuation, electromagnetic interference (EMI), or structural damage to the aircraft. Antenna installations show a consistent pattern in the extensive use of dissimilar metals, a lack of consideration during design to the problems of moisture and fluid intrusion, and inconsistencies in the maintenance materials and procedures provided on like antennas installed in different aircraft types. These, problems when considered collectively, have created both system reliability degradation and a significant consumption of maintenance manhours. Antenna and antenna mount corrosion is especially common to pressurized aircraft, and this is particularly true to lower fuselage installations. When the aircraft is pressurized, various liquid contaminants, including toilet leakage, oil and hydraulic fluid, are forced into any crack, crevice, or fitting available; and there, awaiting destruction, is the inverted antenna bottom and antenna-mount fasteners together with cable connectors. The lower fuselage antennas of non-pressurized aircraft are subject to the same problems. Corrosion just takes a little longer. Upper fuselage antennas are subject to infiltration of electrolyte through condensation and aspiration.

In an attempt to alleviate the antenna corrosion problem, a program was undertaken to determine improved corrosion preventive materials and processes. Representative antenna installations were selected for a fleet evaluation of these maintenance procedures. A test plan was developed that provided the guidelines for conducting the fleet evaluations to assess the effectiveness of these materials and processes. Under Commander, Air Force Pacific (COMNAVAIRPAC) and Commander, Air Force Atlantic (COMNAVAIRLANT) sponsorship and in coordination with the appropriate Fleet Wings, the test plan maintenance procedures and material applications were applied to various types of aircraft antennas. The test period covered 180 days.

The antenna installations selected for evaluations are listed in Table 2. The main basis of selection was that the antennas should represent the different types each with its own distinctive corrosion problems. For example, the P-3 HF Long Wire antenna is subject to corrosion and arcing due to water intrusion into the tensioner assembly and the insulator; the H-46 radio antenna has a whip antenna mounted on the lower skin that has a particular problem due to water entrapment around the electrical attachment inside of the fuselage; and the A-7 Lower TACAN/IFF antenna has a major problem due to the presence of water and other fluids in a bathtub-like area where the coaxial lead penetrates the fuselage skin to the antenna. Similarly, the H-3 No. 1 UHF/Comm Normal (lower) and Alternate (upper) antennas are skin mounted and require a conductive gasket between the antenna base and the skin. These antennas are subject to the same moisture intrusion as the A-7 aircraft, yet the A-7 installation requires no conductive gasket. The H-3 Doppler has a particularly bad problem because that portion of the antenna interior to the aircraft is located in the fuselage low point area and, therefore, subject to a variety of standing fluids.

Table 2, also, lists the corrosion maintenance data for the selected antenna. The list contains the total maintenance actions reported total related corrosion maintenance actions and corrosion percentage. The numbers are based on the corrective maintenance actions performed at the first two levels of maintenance; the organizational or squadron level and the intermediate level. The numbers reflect the magnitude of the corrosion problem in these antennas. The corrosion maintenance actions attributable to corrosion damage range from 11 to 85%.

Selections of materials for this fleet level corrosion control were based on the following considerations:

1. There should be no detrimental effects on the operation of systems or components.

2. They should possess demonstrated effective corrosion preventive properties.

3. Insofar as possible, they should be materials that presently are available in the Naval Aviation supply system.

During the implementation of the test program these procedures were applicable to any of the rigid type antenna bases (blade, whip, or long wire mast base). The step-by-step actions for cleaning, application of corrosion preventives and sealing of these antenna bases were:

a. Removed dirt, oil, and grease from contact surfaces of the antenna and aircraft skin using cleaning cloth dampened with dry cleaning solvent.

b. Removed minor surface corrosion with an abrasive mat.

c. On areas where the corrosion products were abrasively removed, applied Chemical Conversion Coating, MIL-C-81706, Class 3, to the bared surface. The Class 3 material was used because it provides a thinner coating with lower electrical resistivity.

The procedure is applicable to the A-7 aircraft lower tACAN/IFF antenna, shown in Figure 2, and was evaluated on two A-7E aircraft.

Since the A-7 lower tACAN/IFF antenna installation did not require a conductive gasket, the following mounting procedures were used:

a. Removed anodize on screw countersink areas of antenna base in order to provide good electrical conductivity from the base to the screws.

b. Applied Chemical Conversion Coating, MIL-C-81706, Class 3, on bared countersink areas.

c. Applied an even coating of Corrosion Preventive Compound, MIL-C-16173, Grade 4, on both the aircraft skin surface and the flat side of the antenna base which mates against the aircraft skin. The Grade 4 material is a soft, tacky to the touch, coating when it dries and has been used for many years as a general preservative on naval aircraft.

d. Conducted electrical resistance test to check for a good grounding connection. The grounding specification requires the resistance not to exceed 0.1 ohms. (The milliohmmeter reading for these antenna installations were both 0.02 ohms.)

e. Applied a fillet of corrosion inhibited polysulfide sealant, MIL-S-81733, Type II, around the outside of the antenna base on one aircraft and a fillet of MIL-S-8802 polysulfide sealant without inhibitors on the antenna on the other aircraft to form a watertight seal.

f. Covered the fastener heads with Corrosion Preventive Compound, MIL-C-16173, Grade 4.

Corrosion inside of an antenna coaxial connector is a principal cause of antenna performance degradation (Figure 3). Therefore, the cleaning and preserving of the antenna connectors is important to reduce the effects of moisture intrusion. Throughout the test program the cleaning and preserving of these connectors were accomplished during the various installations by the following procedures:

a. With the connector sections mated, corrosion was removed with an abrasive mat.

b. Connectors were opened and internal sections were cleared.

c. The internal areas were sprayed with a water displaying corrosion preventive compound MIL-C-81309, Type III. The MIL-C-81309 material forms an ultra thin tacky (soft) film that is designed so that it is displaced by the wiping action of a sliding electrical contact, yet the film is self-healing (reforms) in non-contact areas after displacement. The resultant lack of disruption to DC continuity through the male/female type of connections due to the MIL-C-81309, Type III, film has been well established.[3,4]

d. The connectors were then mated and a coating of another water displacing corrosion preventive compound, MIL-C-85054[5], was applied to the exterior surface of the connector. This material dries to a relatively thick (1 to 2 mils) hard, clear finish and has been used successfully on navair aircraft to protect exterior skin surfaces in areas where paint has chipped or cracked leaving exposed bare metal.

From the reports submitted by the designated fleet squadrons at the start, at the 28 days inspection intervals, and at the completion of the evaluation when the antennas were removed the following results were summarized.

a. Throughout the 180 day evaluation, all the test items were reported from excellent to satisfactory, and none showed evidence of corrosion or problems with the materials used.

b. All reports indicated that the solvents, cleaning materials, and other maintenance chemicals, had no effect on the sealants or corrosion preventive materials applied to the test items.

c. Throughout the evaluation period, there was only one reported failure. This was on the ADF antenna on the SH-3H helicopter. The failure was discovered during troubleshooting of a discrepancy in the system. When the antenna was removed approximately 3 ounces of water ran out of the antenna installation area. No corrosion, however, could be detected on the antenna and there was no indication that the presence of this water was the cause of the functional failure of the ADF antenna.

Upon removal of the A-7E lower tACAN antenna it was observed that a combination of fluids, mostly hydraulic oil and water had collected on the internal contact surfaces, however, the corrosion preventive compound MIL-C-16173 Grade 4 prevented the fluids from affecting the antenna and the aircraft mounting area. There were no visible signs of corrosion.

When the antenna connectors were disconnected they were in the same condition as when they were connected at the beginning of the evaluation period. There was no evidence of external connector corrosion. As Figure 4 shows the antenna coaxial connector appears to be clean after the six month test even through fluids and foreign matter from the inside of the aircraft are all around the base of the connector.

While it is significant that corrosion was prevented, no method evaluated was able to seal the lower fuselage skin opening through which the co-ax cable connects to the antenna. In many installations there is no practical access to the skin opening from the inside of the fuselage, hence sealing around the coax cable after the antenna was installed could not be done. In such cases, sealing around the outside base of the mounted antenna stopped moisture intrusion into the antenna base to skin interface from only one of the two possible entry areas.

SPECIAL COAXIAL CONNECTOR TESTING

Special testing of coaxial connectors was conducted [6] to assure that the MIL-C-81309 type III water displacing corrosion preventive material used on the internal contact areas would cause no detrimental effects. Traditionally no preservatives have been used inside of a coax connector because of fears that any foreign material would alter the characteristic capacitance created by the spacing and insulation between the inner and outer conductors. This characteristic is particularly critical in those lines for which changes in capacitance is used as a sensor in the system-such as in a capacitive type of fuel quantity indicating system. Any change in the dielectric between the inner and outer conductor also can affect the impendance of an antenna line (connector).

Special tests with relatively sensitive measuring equipment were made to determine the electrical (RF transmission) effects incurred by the use of MIL-C-81309, Type III, Water Displacing Corrosion Preventive Compound in coax connectors. The tests were conducted using TDR (Time Domain Reflectometry) and FDR (Frequency Domain Reflectometry) equipment to sweep a coax assembly over a frequency range. Two runs were made on the line/connector read assembly with no corrosion preventive applied to determine the repeatability of the test. Following that, runs were made with MIL-C-81309, Type III, Class 2, applied to both sections (male and female) of the contractor. No attenuation of signal or change in characteristic impedance resulted from the presence of MIL-C-81309 material in the coaxial connectors over the frequency range measured.

Considering the large number of electrical connectors in a modern aircraft, connector water and corrosion damage cause some of the most costly repairs in the Navy's avionic maintenance business. The major problem with connectors is that of water intrusion or fluid contamination that causes corrosion, insulation damage, short circuits, fire, signal loss or intermittancy, wire failure through insulation and/or connector damage and grommet seal swell or shrinkage.

Connector shell corrosion occurs when protective finishes are damaged and expose the base metal. Visual inspection of the outer surface of connectors is not always a good indication of their condition. Many connectors that outwardly appear acceptable are in fact heavily corroded internally and are impossible to decouple without component damage.

The use of a thin electroless nickel plating over 6061 aluminum on connector shells has caused serious corrosion problems as shown in Figure 5. Cracks develop in the nickel plating and when the surface is wet a galvanic cell is created with the aluminum corroding sacrificially. Figure 4 illustrates the effects of this galvanic corrosion on two coaxial connectors.

In an attempt to correct this problem, Jankowski [7] evaluated coatings for electrical connector shells. The effort led to the use of a duplex nickel-cadmium plating, which, while not preventing corrosion, does provide improved corrosion protection. The use of water displacing corrosion preventive compounds provides additional protection. The use of non-metallic connector shells, however, represents an approach which may completely eliminate this problem.

New developments in injection molded reinforced polymeric materials make them viable candidates for connector applications, avionic enclosures and fittings. Ease of fabrication and promising mechanical properties are some of the reasons these materials are attractive alternatives to metals. Additionally, these resins can be reinforced with chopped conductive reinforcements such as graphite, metallized graphite and stainless steel to provide electrical conductivety and EMI shielding.[8 9 10] Secondary schemes such as metallic coatings and platings can be utilized to supplement shieldings from conductive reinforcements. Connectors with shells fabricated from a 40% graphite chopped fiber reinforced polyphenylene sulfide thermoplastic composite material were installed in the right wheel well switching assembly on four F-14 aircraft in September 1983. This connector performs a non-critical function in the counting accelerometer system and due to its location is exposed to the severest environmental conditions. After more then three years of exposure to the service environment that there is no evidence of deterioration, as shown in Figure 6, and no electrical problems have occurred and no maintenance has been performed on any of the connectors.

Some 40-50% of the weapon removal assemblies removed from an aircraft for cause are returned to a servicable condition by printed wiring board reseating. In a sense, reseating is a form of localized cleaning of corrosion from edge connectors. The vulnerability to this failure mode for the typical blade plug-in type of edge connectors is dependent upon the positioning of the PWB within the equipment and the severity of the environment within the equipment. PWBs mounted horizontally are especially susceptible to accumulations of dust, dirt, debris, moisture condensation and spillage. Vertically positioning PWBs minimizes such an accumulation of contaminants on the board (and allows better convection cooling). From a corrosion and reliability standpoint, the poorest location for edge connectors on a vertically mounted PWB is along the lower or bottom edge. Moisture and hygroscopic debris will collect along this edge. There are a number of instances, where, due to inadequate housing drainage, the lower edge of the PWBs and the edge connectors have been immersed in standing water. It is recognized that, from a convenience viewpoint, it is very handy to be able to remove a lid, lift out a PWB, and drop in (pressing down to seat) the replacement PWB. To minimize susceptibility to corrosion, however, the PWB edge connectors should be mounted on a vertical edge or the back of the board - not the bottom.

Normally, equipment bay doors must maintain r.f. and d.c. electrical continuity between the door and the surrounding airframe to prevent EMI (electro-magnetic interference) both from entering installed equipment as well as radiating externally to the aircraft from the installed equipment. Because of the large size of most equipment bay doors, very close spacing of fasteners as a means of controlling EMI becomes impractical due to maintainability penalties. Indeed, the space between fasteners can act as a slot antenna greatly increasing the EMI problem.

To prevent EMI leakage, conductive gaskets are often used to provide the continuity needed to preclude the passage (in or out) of r.f. or other forms of radiated energy. The conductive EMI gaskets achieve their conductivity by metallic particle or mesh embediment in the gasket or seal. Frequently, this embediment is a dissimilar metal that is very cathodic to the door and airframe skin. Typically, silver, copper or graphite has been placed in electrical contact with aluminum skin. The products of this corrosion are insulative and severely degrade the electrical effectiveness of the EMI gasket. The wire mesh embediment type of gasket also can be subject to wicking of moisture along the embedded strands with resultant corrosion. The inclusion of the conductive materials in the elastromeric gasket degrades the capability of the gasket to perform the sealing function, and the mating of the highly conductive metals to the aluminum housing, doors, aircraft skin, etc., creates bimetallic couples that will severely corrode (and destroy the EMI function) if the seal is less than perfect. In short, the two functions being attempted with an EMI gasket appear to be mutually incompatible.

A possible solution to this problem is the application of water-displacing corrosion preventive compounds such as MIL-C-81309, Type III, on the exposed aluminum surfaces where the EMI gasket metallic particles can penetrate the compound so as to maintain the integrity of the system. This method requires reapplication of the compound each time the integrity of the seal is broken. This puts the burden of continued reliability on the repair technician. A gasket configuration with separate provisions for the EMI and the environmental protection requirements is the best technology available at the present time. This requires an environemntal gasket on both sides of the EMI gasket. Assure the outside protective surface finishes go around the corners and under the environmental gasket.

CORROSION PREVENTION

When an avionic corrosion prevention/control program was established by the Naval Air Systems Command, a major emphasis of the program became the preparation of a Fleet maintenance manual. The lack of preventive maintenance guidelines had been recognized as a contributing factor for the high maintenance requirements for airborne electronics. In May 1978, NAVAIR 16-1-540, Avionic Cleaning and Corrosion Prevention/ Control Manual, was issued to the Fleet. The manual provides instructions for inspecting for and recognizing corrosion in its early stages and identifies materials and procedures necessary for cleaning and corrosion control. The manual[11] revised in 1981 has been adopted by the U. S. Air Force and Army as a tri-service document.

A prototype cleaning facility was established to evaluate the effectiveness of various cleaning methods for avionic equipment. The results of this study determined the optimum types of cleaning and corrosion removal equipment to be supplied to the maintenance activities for use on avionics.[12]

Since the best and ultimately least expensive time to stop corrosion is at the design stage, a program was initiated to develop a designers' guide for avionic corrosion prevention and control. The design[13] guide titled, "Design Guidelines for Avionics Corrosion Prevention and Control" was written and issued as NAVMAT P 4855-2, June 1983. The guide identifies critical design features, structural configurations, materials, material combinations and inadequate corrosion protection methods that have led to poor reliability and high maintenance requirements for avionic equipment placed in the Navy's severe operating environment. This guide is intended to provide an awareness of the corrosion problems that develop on the Navy's equipment and provide design methods that can be used to avoid or minimize them. It is not to be the intent of this guide to dictate design criteria, but to document current corrosion problems so that they may be considered and avoided in the future.

CONCLUSIONS

Corrosion and environmental degradation being natural phenomena will never be eliminated, but it is reasonable to expect that the problems that do develop in the avionics systems in the future can be less severe and better controlled than those presently being encountered. However, this goal can be achieved only through an aggressive technological effort directed towards the understanding of failure mechanisms, development of new improved corrosion control materials and methods, and the prudent utilization of innovative protection technology in the design, manufacture and service life of the avionics equipment.

REFERENCES

1. Carrato, A.F., Shaffer, I.S. and Richwine, R.H., "Corrosion in Naval Aircraft Electronic Systems", National Association of Corrosion Engineers Conference, New Orleans, LA, October 1978.

2. Shaffer, I.S., Carrato, A.F., and Hoffner, J.A., "Aircraft Antenna Corrosion", Proceedings of the 1978 Tri-Service Conference on Corrosion.

3. Ketcham, S.J. and DeLuccia, J.J., "Recent Developments in Materials and Processes for Aircraft Corrosion Control", AGARD Conference Proceedings No. 315, April 1981.

4. Soroka, J., "Failure Analysis Techniques for Electronic Devices and Components", Report No. NADC-78091-60, Naval Air Development Center, Warminster, PA 1980.

5. Pilla, G.J., and DeLuccia, J.J., "A Corrosion Preventive Compound for Aerospace", Metal Progress, May 1980.

6. De Long, G.E., Myrben, L.C , Carrato, A.F. and Shaffer, I.S., "Aircraft Antenna and Electrical Bonding Corrosion Control", Report No. NADC-8009-60 NADC, Warminster, PA, April 1980.

7. Jankowsky, E.J., "Coatings for Electrical Connector Shells", Report No. NADC-76274-30, Naval Air Development Center, August 1976.

8. Simon, R.M., "EMI Shielding Can Be Made of Conductive Plastics", Ind. Res. and Dev., 1982.

9. Buckley, L.J., Shaffer, I and Trabocco, R., "Physical and Mechanical Properties of Conductive Composites", SAMPE Quarterly, Vol. 15 No. 4, July 1984.

10. Reilly, J.J., Thoman, S.J. and Lin, W.W., "Characterization of Hybridized Conductive Fiber Reinforced Nermoplastics", International SAMPE Technical Conference Proceedings, Vol. 18, 1986.

11. Naval Air Systems Command, Technical Maintenance Manual 16-1-540, "Avionic Cleaning and Corrosion Prevention/Control, September 1981.

12. DeLong, G.E., Gordon, W.G., Sinclair, J.A. and Reilly, J.J., "Effectiveness of the Avionics Corrosion Control Facility at AIMD, NAS Niramar", Report No. NADC-86004-60, February 1986.

13. Department of the Navy P4855-2, "Design Guidelines for Prevention and Control of Avionic Corrosion, June 1983.

TABLE 1. EFFECTS OF CORROSION ON AVIONIC COMPONENTS

COMPONENT	FAILURE MODE
ANTENNA SYSTEMS	Shorts or changes in circuit constants and structural deterioration.
CHASSIS, HOUSING, COVERS, AND MOUNTING FRAMES	Contamination, pitting, loss of finish and structural deterioration.
SHOCK MOUNTS AND SUPPORTS	Deterioration and loss of shock effectiveness.
CONTROL BOX MECHANICAL AND ELECTRICAL TUNING LINKAGE AND MOTOR CONTACTS	Intermittent operation and faulty frequency selection.
WATER TRAPS	Structural deterioration.
RELAY AND SWITCHING SYSTEMS	Mechanical failure, shorts, intermittent operation and signal loss.
PLUGS, CONNECTORS, JACKS AND RECEPTACLES	Shorts, increased resistance, intermittent operation and reduced system reliability.
MULTI-PIN CABLE CONNECTORS	Shorts, increases resistance, intermittent operation and water seal deterioration.
POWER CABLES	Disintegration of insulation and wire/connector deterioration.
DISPLAY LAMPS AND WING LIGHTS	Intermittent operation, mechanical and electrical failures.
WAVEGUIDES	Loss of integrity against moisture, pitting, reduction of efficiency and structural deterioration.
RADAR PLUMBING JOINTS	Failure of gaskets, pitting and power loss.
PRINTED CIRCUITS AND MICROMINIATURE CIRCUITS	Shorts, increased resistance, component and system failures.
BATTERIES	High resistance at terminals, failure of electrical contact points and structural deterioration of mounting.
BUS BARS	Structural and electrical failures.
COAXIAL LINES	Impedance fluctuations, loss of signal and structural deterioration of connectors.

TABLE 2. ANTENNA CORROSION CORRECTIVE MAINTENANCE

Aircraft	Nomenclature	Total Maintenance Actions	Total Corrosion Maintenance Actions	Percent Corrosion
A-7	Lower TACAN/IFF	281	240	85%
H-3	No. 1 UHF/Comm (normal)	155	103	66%
H-3	No. 1 UHF/Comm (alternate)	58	33	57%
P-3	Long Wire DF Sensing	186	21	11%
H-46	Long Wire DF Sensing	133	28	21%
H-3	Receiver Transmitter (Doppler)	653	139	21%

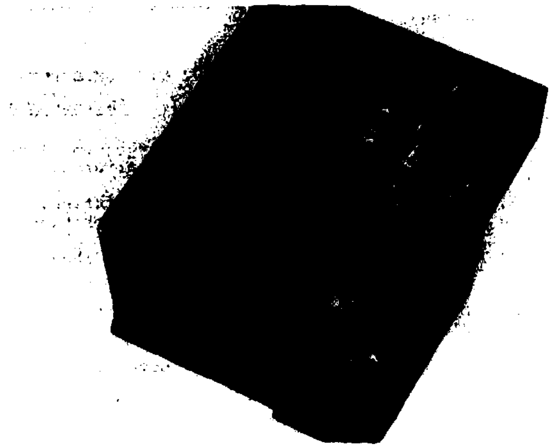

FIGURE 1. CORRODED A-6 POWER SUPPLY SUBASSEMBLY

FIGURE 2. A-7 LOWER TACAN/IFF ANTENNA

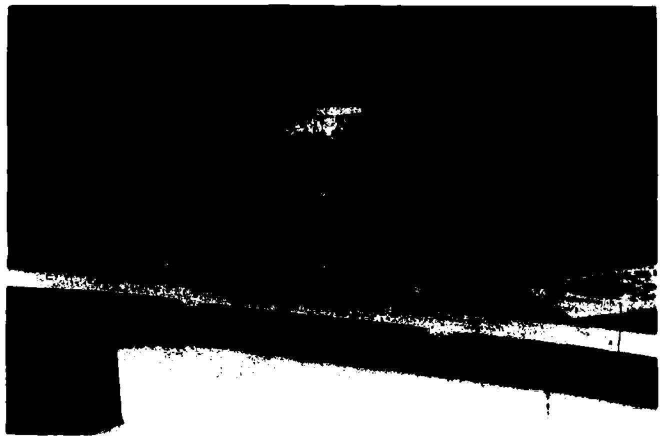

FIGURE 3. CORROSION ON LOWER TACAN/IFF ANTENNA COAXIAL CONNECTOR

FIGURE 4. CORROSION PROTECTION RESULTS OF LOWER TACAN/IFF ANTENNA

FIGURE 5. GALVANIC CORROSION OF NICKEL PLATED ALUMINUM COAXIAL CONNECTORS

FIGURE 6. COMPOSITE CONNECTOR ON F-14 RIGHT WHEEL SWITCHING ASSEMBLY

AD-P005 751

CORROSION OF ELECTRONIC COMPONENTS

by

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SUMMARY

The Materials Laboratory Electronic Failure Analysis Group supports ~~U.S. Air Force~~ USAF electronic systems in the areas of materials and manufacturing processes. It has been established that a large majority of electronic failures are caused by materials and manufacturing process defects. We have found that corrosion of electronic components is the cause of failure in about 20% of the items submitted to us for investigation.

Airframe corrosion prevention requirements are well specified by MIL-STD-1568, MIL-STD-1587, T.O. 1-1-2, and MIL-STD-889. It would be beneficial to the Air Force if corrosion prevention in electronic systems were ~~also~~ well documented. Existing documents, such as T.O. 1-1-689 and NAVAIR 16-1-540, are a step in the right direction. However, compulsory MIL specifications should be applied to Air Force electronic corrosion prevention. This is essential because corrosion in Air Force electronic systems contributes significantly to system failure.

Failure analysis investigations ~~with which we have been concerned include~~ aircraft circuit breakers, an antenna, printed wiring boards, a fuse, a linear steering position transducer, a stepper motor, an accelerometer, a disk recorder head, and electrical connectors ~~will be~~ presented. The cause of failure ~~will be~~ identified and possible means of preventing similar failures ~~will be~~ presented.

I. INTRODUCTION

The Electronic Failure Analysis Group of the Air Force Wright Aeronautical Laboratories' Materials Laboratory has investigated a large number of electronic and electrical failures. It has been established that about eighty-three percent of these failures are caused by materials and manufacturing process defects. Also, it has been verified that about twenty percent of the failures are caused by corrosion problems.

II. ANALYSIS TECHNIQUES

Moisture and contamination penetration into electronic systems has many detrimental effects, corrosion being one of these. In most electronic systems the geometries have been minimized for faster signal processing and higher density. This means that most metallizations are thin, or small in cross-sectional area, and that the individual metallizations are close together. In systems such as this, trace amounts of moisture and contamination may cause system failure. If the aluminum metallized surface of an integrated circuit is contaminated and if moisture is present, a slight amount of corrosion may result in an open integrated circuit conductor. This extreme sensitivity requires special caution when dealing with corrosion in electronic systems. Failure modes in electronic components and systems may be identified and related to field failures with environmental testing techniques. Figure 1 shows a typical twenty-four hour temperature and humidity cycle.

III. EXAMPLES OF ELECTRONIC AND ELECTRICAL CORROSION

The following are a few representative examples of corrosion induced failures.

A. Circuit Breakers

Numerous aircraft circuit breakers, Figure 2, have been identified as failed because their contact resistance when closed was considered too high. A number of circuit breakers from several different manufacturers were tested in the laboratory to determine the cause of the high resistance. The circuit break contacts were identified as either tungsten/silver or cadmium/-silver mixtures. Nine circuit breakers were exposed to a ten day humidity test (40°C and 95% RH). A destructive physical analysis of the parts found a small amount of corrosion on the tungsten/silver contacts. Because of this, a twenty day humidity test (49°C and 95% RH) was conducted on two contacts which had been cross-sectioned. After the twenty day test, the tungsten silver contacts were severely corroded while the cadmium/silver contacts exhibited very little corrosion, Figures 3 and 4.

A forty-eight hour salt fog test (35°C, 5% NaCl, pH 6.5 to 7.2, 1 to 2 cc/hr/80 cm^2 condensation rate) was conducted on seven of the circuit breakers. Two of the circuit breakers failed. This was caused by salt condensation on the contacts, Figure 5.

The results of our analysis indicate that the tungsten/silver contacts corrode much worse than the cadmium/silver contacts. Braze fluxes used to joint the contacts to the copper arm may contribute to corrosion.. The contacts in all circuit breakers are improved by the mechanical wiping action of opening and closing the contacts several times. This should be done at periodic intervals. If the conduction of large currents is not required the cadmium/silver contacts show superior resistance to corrosion.

B. Antenna Marker Beacon

A corroded antenna marker beacon, Figure 6, was removed from an aircraft so that the source of corrosion could be determined. The beacon was x-rayed, Figure 7, and corrosion sites were visible in the radiograph. The antenna was opened and found to contain a polyamide foam, Figure 8. The antenna blade was removed from the foam, Figure 9, and found to be corroded too. Both the housing and blade were found to be aluminum. The housing was found to be plated with electroless nickel, Figure 10, and the blade was plated with a copper strike followed with a tin plate, Figure 11. It is believed that both the nickel plate and the copper/tin plate were porous. This permitted the penetration of moisture to the plating and aluminum interface. The presence of moisture and the anodic relationship of aluminum to nickel, or tin, resulted in a galvanic cell which caused pitting corrosion in the aluminum, Figures 12 and 13. These plating systems were used to maintain a high electrical surface conductance on the aluminum components. The corrosion has resulted in non-conductive surfaces which affect the electrical performance of the antenna. It was recommended that instead of plating the aluminum a chromate conversion coating be used.

C. Printed Wiring Boards

1. Flux Contamination

a. Dual In-line Packages

A printed wiring board was removed from an aircraft because of short circuits on the board, Figure 14. Blue-green corrosion products appeared around and under Dual In-line Packages (DIPs) on the board, Figure 15. A scanning electron microscope was used to analyze the corrosion products with characteristic x-ray analysis. Copper chloride was detected in the corrosion residue. Chlorides are a common contamination resulting from active solder fluxes and poor cleaning processes. It was recommended that a rosin type solder flux be used and that a board cleanliness test be performed after cleaning.

b. Conductor Traces

A ground base radar system was removed from nine months of storage to be tested. All electrical systems failed due to short circuits in many of the multilayer printed wiring boards. Upon examination the printed wiring boards appeared to have corroded conductor traces. Contamination and corrosion products had migrated to regions between conductor traces so that they were shorted out. See Figures 16 and 17. With characteristic x-ray analysis it was established that the contamination resulted from solder flux. A different cleaning procedure was recommended.

2. Flux on Board Components

Components from a printed wiring board have also been found to be contaminated with solder fluxes. Figure 18 shows a diode taken from a board. Figure 19, shows the corroded leads on this diode. Inadequate removal of flux residues causes many corrosion problems.

3. Water Soluble Flux

The use of a highly reactive solder flux may sometimes have unexpected consequences. Of course, the reactive flux makes the soldering procedure easier. Components or boards which have poor solderability may sometimes be used, or, some other device defects may be overcome but usually the reactive flux contaminates some parts of the electronic system so that it eventually causes more problems than it fixed.

A reactive water soluble flux was used on a number of printed wiring boards because some of the component leads exhibited poor solderability. The flux had a high chlorine content. During the soldering operation some of these chlorides were absorbed in the epoxy/fiber glass board surface. After soldering, the boards are cleaned and conformally coated. This traps the flux near the surface of the board. The board cross-section is shown in Figure 20. The x-ray map for this area is shown in Figure 21. This chlorine may eventually affect the copper conductors in the board because the conformal coating will absorb moisture which could result in hydrochloric acid. Without the reactive water soluble flux this chloride surface contamination does not occur. If the components to be soldered are handled properly the soldering operation may be accomplished with less reactive fluxes. This is the best procedure.

D. Vacuum Tubes

Triode amplifier tubes were failing due to severe corrosion exterior and interior to the tubes, Figure 22. It was determined that the contaminant was a chloride and its source was most likely a highly corrosive chloride flux. Figure 23 shows localized corrosion on the outside of the tube and Figures 24 and 25 show the corrosion on the inside of the tube. Figure 26 shows a tube cross-section with the entrapped green corrodent clearly visible. It was recommended that all fluxes be thoroughly cleaned from the tube before sealing.

E. Fuse

After storage for several years some fuses were tested. The fuse failure rate was exceedingly high. The cause of this high failure rate required identification. Figure 27 shows the electronics when removed from the package. Note the white vibration dampening foam between the circular printed wiring boards. Upon analysis the foam was identified as polyvinyl

chloride. The circular boards were examined and it was found that they were heavily contaminated with chlorides. One of the boards was placed in a humidity cabinet for twenty-four hours with the results shown in Figures 28 and 29. Several failed plastic encapsulated transistors were opened, Figures 30 and 31. The arrow in Figure 30 marks the region in which the aluminum metallization was completely melted. The transistor surface was heavily contaminated with chlorides. It was found that these chloride contaminates were originating from the vibration dampening foam. The chloride penetrated the transistor by wicking up the metal leads extending through the plastic package. The polyvinyl chloride foam was replaced with a polyacrylic elastomer foam. The new foam material does not emit chloride contamination.

F. Steering Potentiometer

A linear feedback potentiometer is often used in the steering system for an aircraft nose wheel. A potentiometer of this type is shown in Figure 32. Several failures of this device have been observed. The cause of these failures was investigated. It was found that the ends of the potentiometer were exposed to the environment. Sufficient moisture and contamination were collected on the potentiometer in this area to cause corrosion. Figures 33 and 34 show corrosion products collecting on the glass header insulation around the incoming electrical wires. These corrosion products were shorting out the electrical leads on the potentiometer. The problem was corrected by providing this area of the potentiometer with sufficient protection to prevent the entrance of the moisture and the contamination.

G. Stepper Motor

Stepper motors are often submerged inside a fuel tank for cooling purposes. Of course, this means that the motor components, Figure 35, are then exposed to the fuel environment. In all cases, there is some small amount of water in the fuel. With sufficient time we have found that this water will hydrolyze polyimide wire insulation. These stepper motors had polyimide insulation on the field coils. After sufficient exposure to the water in the fuel some of the coils appeared as in Figure 36. This defect exposes the copper to the fuel. If some contamination in the fuel is available the copper ions will migrate into the fuel. This produces open circuits in the field coils as shown in Figure 37. This type failure may be avoided by hermetically sealing the field coils from the fuel, or by using a polysulfide insulation.

H. Accelerometer

An aircraft accelerometer was environmentally sealed instead of hermetically sealed. After extended use the accelerometer failed. Several accelerometers were tested in the Combined Environmental Reliability Test (CERT) chamber to establish the failure mode. The stresses used in the CERT chamber were selected to approximate the actual aircraft environment. The stresses included temperature cycling, humidity cycling, and altitude cycling, Figure 38. The accelerometer was electrically operational during a certain part of the cycle. After the accelerometer went through one hundred fifty cycles, it failed. The package was opened, Figures 39 and 40, and it was easily seen that corrosion residues were shorting out various parts of the circuits. This failure may be eliminated by hermetically sealing the accelerometer package.

I. Record Head

Disk recorder heads, Figure 41, were failing at a very high rate. This was happening in an area where the recorder operator was smoking cigarettes. Some of the particulate matter in the smoke was being trapped between the disk and the head. This contamination with the moisture available from the air was causing pitting corrosion in the head, Figure 42. It was recommended that the operator not smoke in the recording area and that the heads not be cleaned with a halogenated cleaning solvent. Use an alcohol.

J. Connector

1. Radar Modulator

The cause of failure of a radar modulator was identified as a corroded connector, Figure 43. Two connectors, one corroded and the other not, were joined by a wire insulated with a silicone rubber which had a chloride content less than 0.16%. The surfaces of both connectors were silver plated. The connectors were cross-sectioned, Figures 44 and 45, and the base material was identified as leaded brass. As shown in Figure 44, the silver plating on the uncorroded connector was 6.7 μm thick. The silver plate on the corroded connector, Figure 45, was 5 μm thick. Both plating thicknesses are too thin for adequate protection. The plating process should meet Federal Specification QQ-S-365C "General Requirements for Electrodeposited Silver Plating". This specification requires a nickel strike and a silver plating thickness of 13 μm. The corrosion was associated with a thin silver plating and it is believed a silver plating of specified thickness will eliminate the corrosion problem.

2. Low Voltage Connector

The corrosion of electrical connectors causes a large number of electrical failures. Figure 46 shows the corrosion on some aircraft connectors. These problems may be minimized when the connectors are installed in a horizontal position; when a loop is placed in the wire so water will not flow down the wire into the connector; when inhibitors are used on the connector pins and receptacle interior mating areas (MIL-C-81309, Type III); and when inhibitors are used on the external connector surfaces (AMLGUARD MIL-C-85054). It is

recommended that an aluminum connector with cadmium plate be used. The possibility of corrosion can be further minimized by using a chromate conversion coating over the cadmium plate.

K. Detector

A microwave detector failed due to corrosion, Figure 47. The ferrite core surface and cavity are shown in Figures 48 and 49. The detector case was constructed of nickel plated aluminum. The cavity lid has been removed and is shown in Figure 50. Note the corrosion along the edge. This corrosion is attributed to delamination of the nickel coating and the exposure of a dissimilar metal couple to high levels of moisture. The nickel coating delamination is the result of a poor plating process. This is usually caused by inadequate cleaning of the aluminum surface prior to plating. The pitting corrosion of the aluminum case and the poor lid-to-case seal allowed moisture to enter the internal case cavity, which resulted in the corrosion shown in Figures 48 and 49.

An alternate plating for the aluminum should be considered. Ion vapor deposited (IVD) aluminum should be used instead of nickel. A better lid-to-case seal should be obtained. This can be accomplished with appropriate gasket material.

L. Nickel/Boron Plated Panels

For many applications materials are required to meet conflicting requirements. An example of this is when metal panels are required to have corrosion resistance and good electromagnetic interference (EMI) protection. Such panels may be used to package electronic equipment.

Twelve nickel/boron coated aluminum plates, Figure 51, were given electrical and environment tests. Samples 1, 2, and 3 were 6062 aluminum and samples 4 and 5 were 2024 aluminum. The nickel/boron coating was 90% nickel with 10% boron diffused into it. A piece was cross-sectioned and it was found that the coating was made in two layers, Figure 52, each layer 0.625 mil thick. The faying surfaces were prepared for test by overlapping the pieces and drilling holes through the panels. The two plates were bolted together with nylon screws, Figure 53. A torque wrench was used to apply one inch pound of torque to each bolt.

The EMI protection requirement is that all faying surfaces maintain a resistance that does not exceed 2.5 milliohms after environmental exposure. A four point probe test fixture, Figure 54, was designed to measure the faying surface conductivity. The outer probes carried one ampere current and the inner probes were used to measure the voltage drop. For all measurements the current was reversed and the resistance values were averaged.

After the specimens were prepared as shown in Figure 53, five of them were submitted to humidity testing and one was kept as a reference. The humidity chamber was set at 95% relative humidity at 120°F for ten days. The specimens were removed after the first twenty-four hours and then every forty-eight hours for a visual inspection and, after re-torquing, a surface resistance measurement. The surface resistance measurements for the specimens are shown in Table I. The condition of sample 1 after the ten day humidity exposure is shown in Figure 55. This sample is typical.

The five samples were disassembled and cleaned with distilled water in preparation for a salt fog test. The chamber was set-up in accordance with ASTM Standard B-117. A five percent salt solution of 95°F and condensation rate of 1-2 mils/hr/80 cm inside the chamber were used to create the salt fog atmosphere. The specimen plates were bolted together again, as during the humidity test, and exposed to the salt fog for 336 hours, or 14 days. The samples were removed periodically for visual inspection and electrical testing. The samples were washed with distilled water, dried for two hours, and re-torqued before being electrically tested. After testing, the samples were then returned to the chamber until 336 hours of testing were completed. The results of the electrical testing are shown in Table II. All five samples exhibited signs of corrosion after 144 hours. The number 4 and 5 samples exhibited severe corrosion, Figure 56. The surface resistances of these samples were higher than the other samples, but still below the maximum of 2.5 milliohms. After 336 hours in the salt fog, samples 4 and 5 again exhibited severe corrosion, Figure 57. Only the surface resistance of sample 4 was above 2.5 milliohms. After electrical testing, the samples were disassembled. The overlapping surfaces of all samples exhibited corrosion, Figure 58. Pictures of the samples with the least and most corrosion are shown in Figures 59 and 60.

The nickel/boron coated aluminum plates passed the humidity testing but they did not do as well in the salt fog testing. The corrosion was most severe when a break occurred in the nickel/boron coating and allowed the salt solution to penetrate into the coating/aluminum interface. The anodic relationship of aluminum to nickel resulted in pitting corrosion of the aluminum and the formation of aluminum oxide. The aluminum oxide is an excellent insulator and will significantly increase the surface resistance of the panel. The plating should be free of surface imperfections and protected from scratches which could break the coating and result in corrosion.

IV. CONCLUSIONS

The examples of corrosion in electronic equipment listed above were obtained from actual case histories, in an Electronic Failure Analysis Laboratory. Of all the projects submitted to this laboratory, 83% of the failures are caused by materials and manufacturing process defects. It was established that corrosion was the cause of about 20% of the failures.

The recommended fixes always interrupt the electrochemical circuit required for corrosion; anode, cathode and electrolyte (so that electrical conduction may take place between the anode and cathode). The fixes either remove the electrolyte, or insulate the anode, or remove the cathode. Once these fixes are accomplished, there is usually a very large cost savings for the customer and a significant improvement in the electronic equipment reliability.

TABLE I. Faying Surface Resistance of Plates Exposed to High Humidity

Sample Number	Average Surface Resistance (microhms) @ 1 ampere					
	Initial	After 24 hrs	After 48 hrs	After 96 hrs	After 192 hrs	Final 240 hrs
1	140	245	256	201	226	183
2	130	282	263	220	208	214
3	134	207	230	219	230	243
4	146	322	205	202	198	202
5	144	374	333	346	356	326

TABLE II. Faying Surface Resistance of Plates Exposed to Salt Fog

Sample Number	Average Surface Resistance (microhms) @ 1 ampere					
	Initial	After 24 hrs	After 48 hrs	After 96 hrs	After 192 hrs	Final 240 hrs
1	198	155	143	203	274	277
2	212	136	134	211	255	260
3	273	162	152	158	155	161
4	220	176	200	799	15369*	20727
5	198	285	298	332	400	632

* [illegible]ceeded 2.5 milliohms

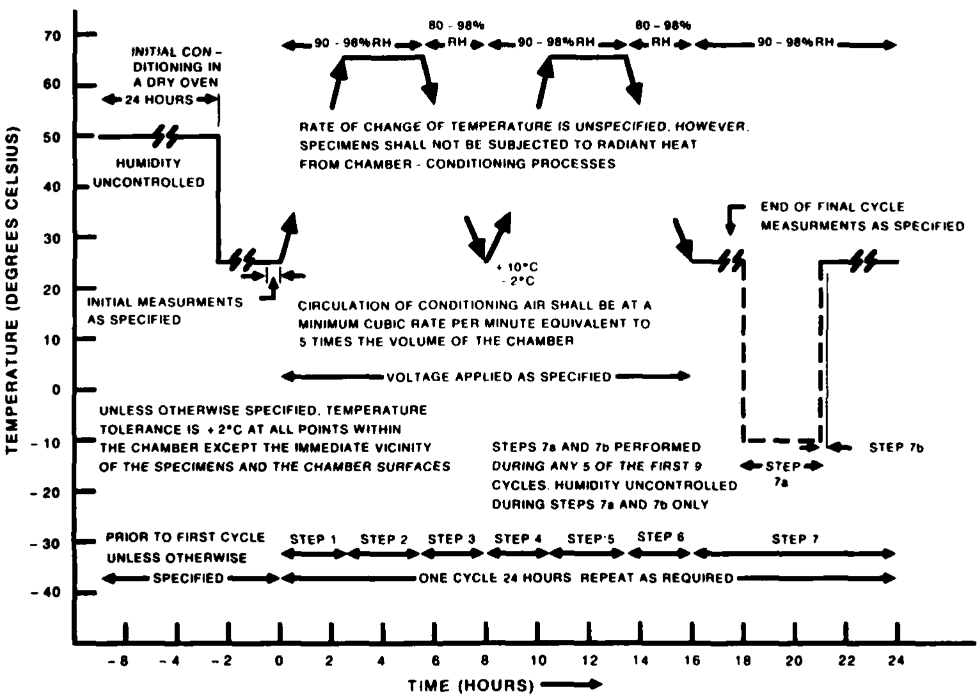

Figure 1. Graphical representation of thermal and humidity cycling.

Figure 2. Exploded view of aircraft circuit breaker.

Figure 3. Cross-sectional view of tungsten/silver contact after twenty day humidity test.

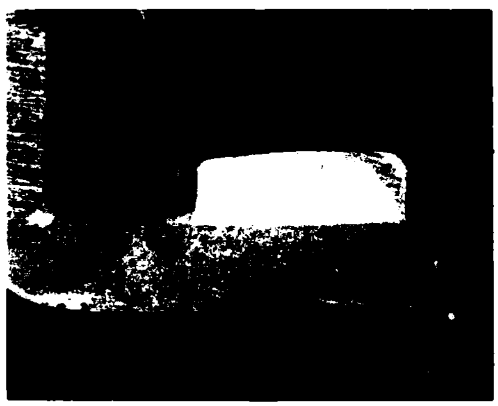

Figure 4. Cross-sectional view of cadmium/silver contact after twenty day humidity test.

Figure 5. Failed contact after forty-eight hour salt fog test.

Figure 6. Failed antenna marker beacon caused by corrosion.

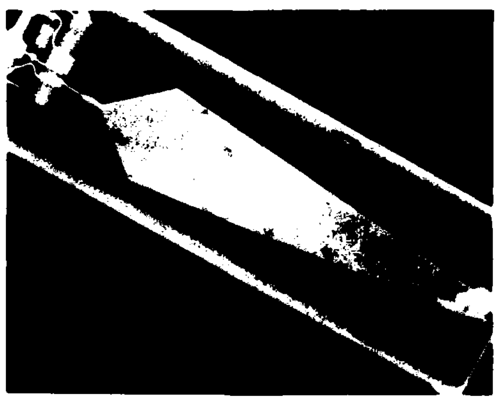

Figure 7. X-ray radiograph shows areas of corrosion.

Figure 8. Polyamide foam inside beacon.

Figure 9. Antenna blade removed from housing.

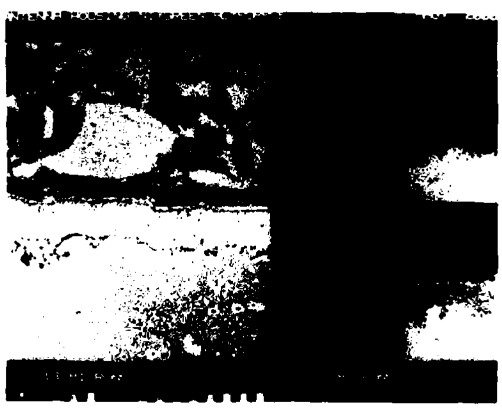

Figure 10. X-ray map of cross-sectional area of nickel plate on aluminum housing of beacon. See Figure 12.

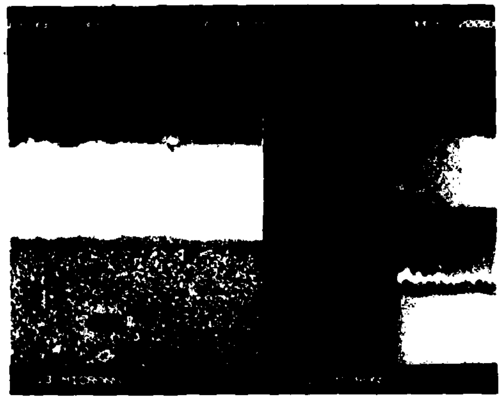

Figure 11. X-ray map of cross-sectional area of copper/tin plate on aluminum blade of beacon. See Figure 13.

Figure 12. Cross-sectional SEM micrograph of nickel plating on aluminum housing of beacon. Note areas of lifted nickel plating.

Figure 13. Cross-sectional SEM micrograph of copper/tin plate on aluminum blade of beacon. Note areas of lifted plating.

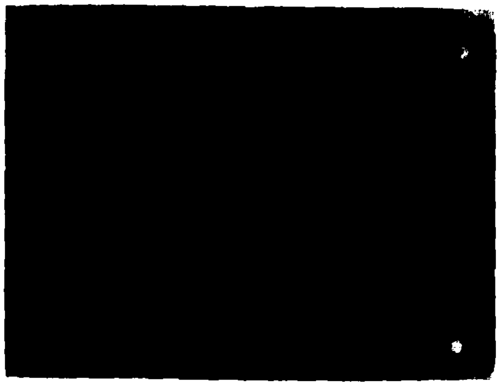

Figure 14. Component side of failed PWB. Note flux contamination on board.

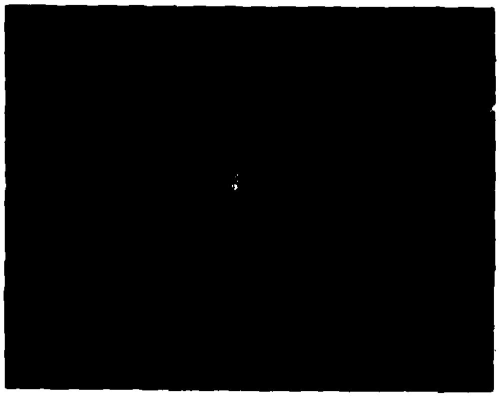

Figure 15. One of the DIPs shown in Figure 14 at higher magnification. Leads are shorted out by flux contamination.

Figure 16. Component side of failed PWB.

Figure 17. Backside of board shown in Figure 16. Note corrosion on conductors and white areas of mealing on board.

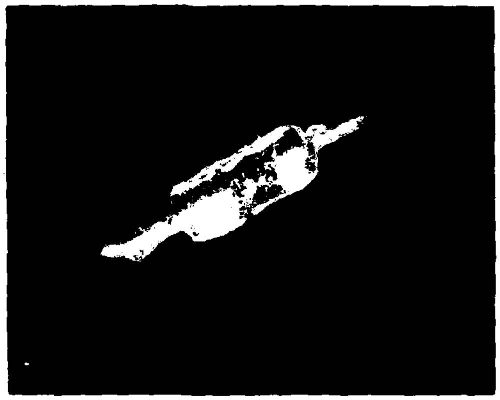

Figure 18. Diode removed from failed PWB.

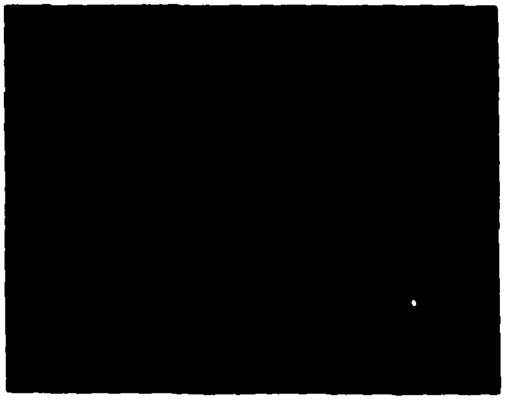

Figure 19. Lead on diode shown in Figure 18. Note corrosion on lead.

Figure 20. SEM micrograph of cross-sectional area of PWB. Constitute parts from the left are: void, conformal coating, solder, copper, and epoxy/fiberglass board matrix. See Figure 21.

Figure 21. X-ray map of area shown in Figure 20. Gray area is copper. Blue region on copper is solder. Green lower central region is chlorine in surface of epoxy/fiberglass board matrix. See Figure 20.

Figure 22. Failed triode amplifier tubes with corrosion interior and exterior to the tubes.

Figure 23. Exterior corrosion on the triode.

Figure 24. Interior corrosion in the triode. Glass envelope has not been removed.

Figure 25. Interior corrosion in the triode. Glass envelope has been removed.

Figure 26. Cross-section of triode shows entrapped corrodent.

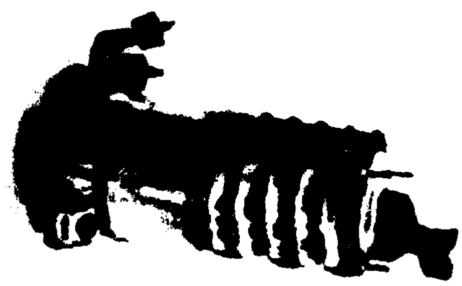

Figure 27. Electronic device with white vibration dampening foam between PWBs.

Figure 28. Corrosion on board resulted from chloride contamination. See Figure 29.

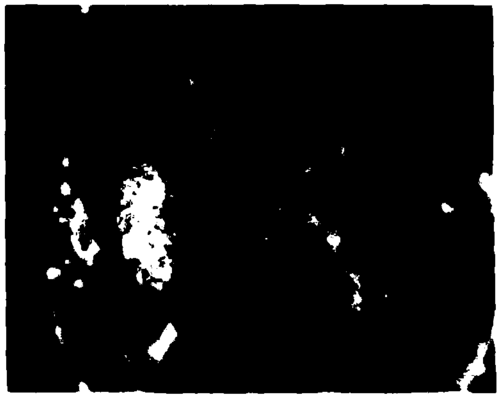

Figure 29. Enlargement of area shown in Figure 28.

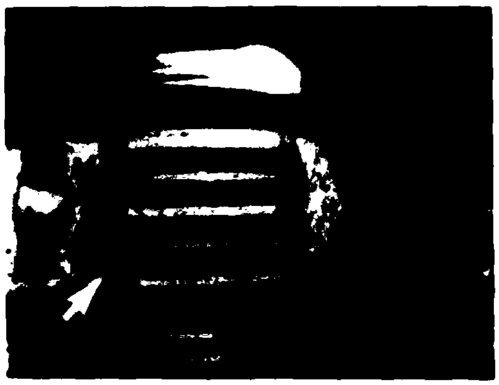

Figure 30. Failed transistor with high surface chloride contamination. See Figure 31. Arrow marks site of open aluminum conductors.

Figure 31. SEM micrograph enlargement of region marked by arrow in Figure 30.

Figure 32. Linear feedback potentiometer.

Figure 33. Arrow marks corrosion residue on potentiometer exterior which shorts out electrical leads.

Figure 34. Enlargement of site marked by arrow in Figure 33.

Figure 35. Exploded view of stepper motor.

Figure 36. Cracked polyimide insulation on field coils.

Figure 37. Arrow marks site of open field coils.

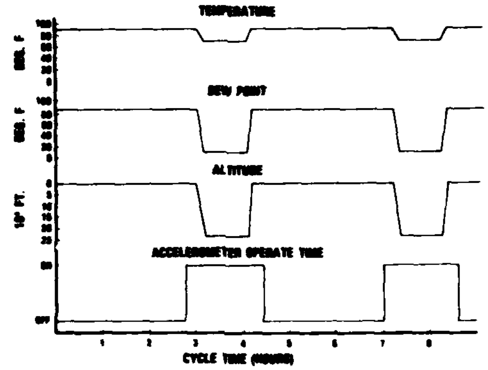

Figure 38. Spectrum of CERT stresses applied to accelerometer.

Figure 39. Failed accelerometer opened for inspection. Arrows mark regions of corrosion.

Figure 40. Enlargement of area shown in Figure 39.

Figure 41. Disk recorder head. Arrow marks metallic head.

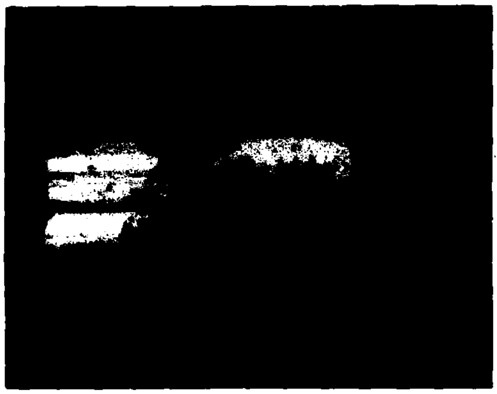

Figure 42. Enlargement of head marked by arrow in Figure 41.

Figure 43. Corroded connector on radar modulator.

Figure 44. Cross-sectional area of good connector.

Figure 45. Cross-sectional area of failed connector.

Figure 46. Corroded electrical connector on avionic equipment.

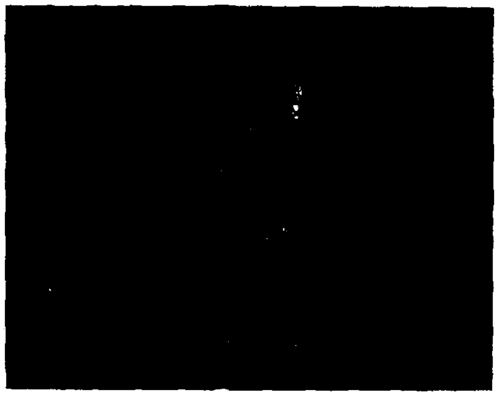

Figure 47. Corroded microwave detector.

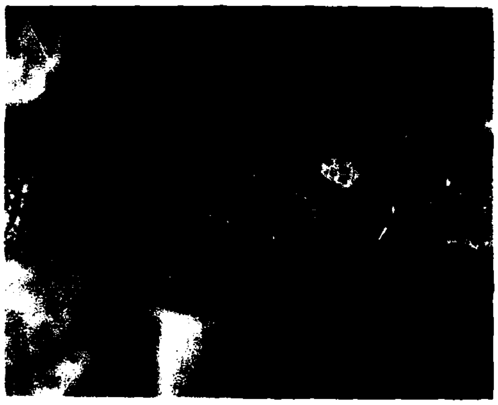

Figure 48. Ferrite core in detector.

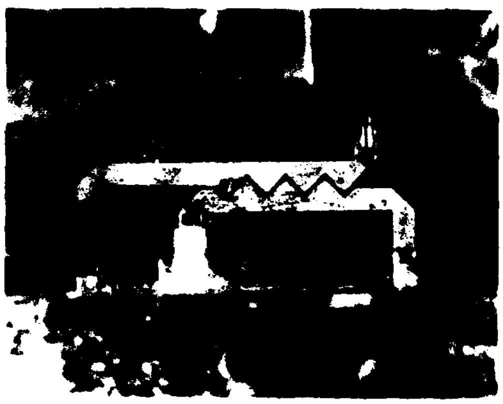

Figure 49. Detector cavity.

Figure 50. Corrosion on the nickel plated aluminum lid.

Figure 51. Twelve nickel/boron plated aluminum panels to be tested.

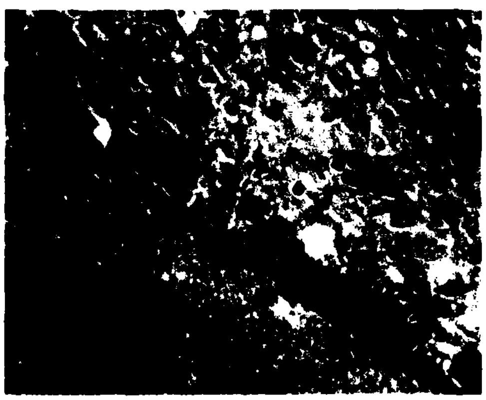

Figure 52. Cross-sectional view of nickel/boron plating on the aluminum panel.

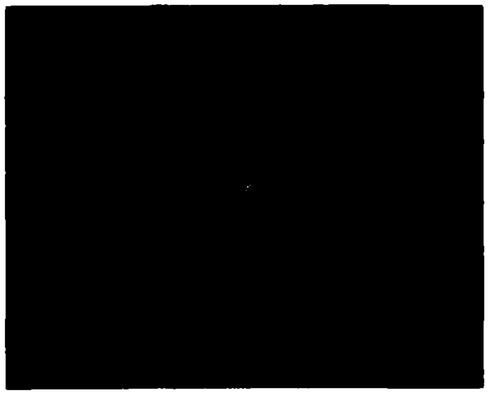

Figure 53. Two panels bolted together with nylon bolts.

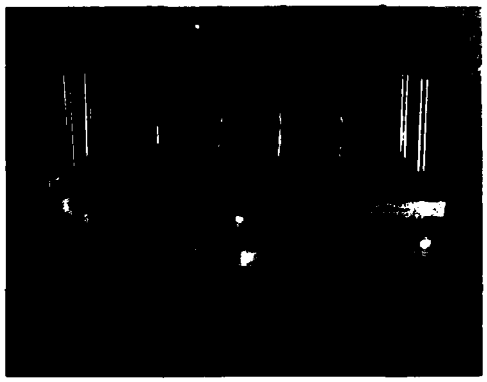

Figure 54. Test fixture used to measure electrical resistance between two panels.

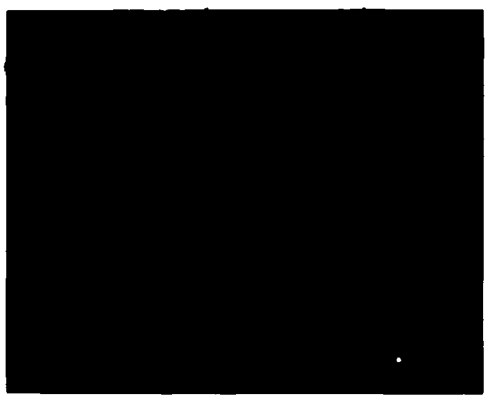

Figure 55. Sample 1 after humidity testing.

Figure 56. Sample 4 after 144 hours of salt fog testing.

Figure 57. Sample 4 after 336 hours of salt fog testing.

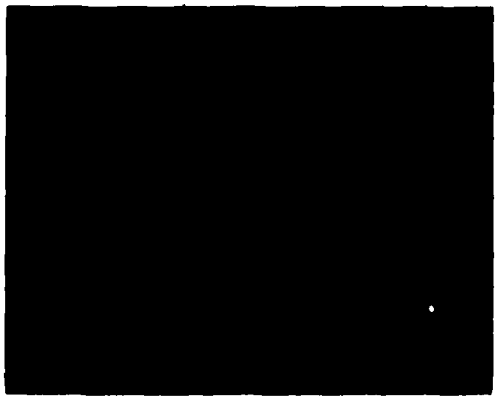

Figure 58. Surfaces of all samples after 336 hours of salt fog testing.

Figure 59. Sample surface with least corrosion after 336 hour salt fog test.

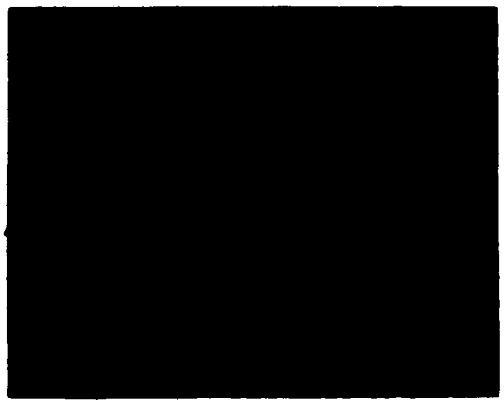

Figure 60. Sample surface with most corrosion after 336 hour salt fog test.

AD-P005 752

US NAVAL AIR FORCE
AVIONIC AND ELECTRICAL SYSTEM CORROSION PREVENTION AND CONTROL MAINTENANCE

by

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1. A study of premature failures of installed avionics, electrical equipment, and systems experienced in US Fleet operational aircraft in the 1960s and early 1970s was reported in reference (1). These failures were caused by corrosion, water intrusion, and other contaminating agents. In order to reverse this trend the Commanders Naval Air Forces US Atlantic and Pacific Fleets (COMNAVAIRLANT) (COMNAVAIRPAC) requested that Commander Naval Air System Command (COMNAVAIRSYSCOM) develop a corrosion prevention and control program for avionics, electrical and installed systems used in naval aircraft. COMNAVAIRSYSCOM tasked the Naval Air Development Center (NAVAIRDEVCEN) to develop the program together with a technical manual. A conference with all interested parties was held in 1976 and action initiated to develop the program and technical manual for use by the fleet technicians.

2. A review was conducted to assess the overall problem.

a. How to clean avionics, remove corrosion, restore protective finishes; what corrosion preventives could be used on avionics without degrading performance of the equipment; who to reclaim equipment that had been exposed to corrosive agent. Each issue required answers.

b. The agents causing corrosion were identified, i.e., salt water, sea environment with 100% humidity, maintenance chemicals, stack gases, high temperature, cyclic temperatures, moisture, galvanic action in the operating environment between dissimilar materials, microbial, insect, bacteria, fungi producing environment, etc.

c. Metallic

What kinds of corrosion can we expect to see?

(1) Uniform surface attack (e.g. Fig.1)

(2) Galvanic (e.g. Fig.2)

(3) Pitting (e.g. Fig.3)

(4) Crevice (concentrated cell)

(5) Intergrannular

(6) Stress

(7) Exfoliation

(8) Erosion

(9) What does it look like? (See Table 1)

d. Non-metallic deterioration

(1) Mechanical failure

(2) Cracking

(3) Swelling

3. The results of corrosion or contamination can cause failure of the equipment or undesirable alteration of its electrical characteristics. The list of all types of material used in avionics would be extensive; most have an ability to function well individually and would last the life of the component. However, the synergistic effect when dissimilar materials are exposed to a corrosive environment is often corrosion.

a. Special Consideration. The control of corrosion in avionic systems is not unlike that in airframes, with procedures useful for airframes being applicable to avionics, with appropriate modifications. The general differences in construction and procedures between airframe and avionics relative to corrosion control are as follows:

(1) Less durable protection system

(2) Very small amounts of avionics corrosion can make equipment inoperative, as compared to airframes.

(3) Dissimilar metals are often in electrical contact.

(4) Stray currents can cause corrosion.

(5) Active metals and dissimilar metals in contact are often unprotected.

(6) Closed boxes can produce condensation during normal temperature changes during flight.

(7) Avionic systems have many areas to trap moisture.

(8) Hidden corrosion is difficult to detect in many avionic systems.

(9) Many materials used in avionic systems are subject to attack by bacteria and fungi.

(10) Organic materials are often used which, when overheated or improperly or incompletely cured, can produce vapors which are corrosive to electronic components and damaging to coatings and insulators.

b. Investigation revealed a second special consideration was microbial, fungi, insects and animals causing corrosion in avionics. See Table 2.

(1) **Microbial, Insect and Animal Attack**

(a) *General.* Microbial attack (which includes mold, bacteria and fungi) creates by-products that will cause corrosion. Modern avionic equipments, because of their complexity, dense packaging, and higher sensitivity, are more susceptible to damage from microbial attack than earlier systems. Mold, bacteria and fungi are living members of the plant world and, in most cases, must have water to live. The organisms causing the greater corrosion problems are bacteria and fungi. In addition to microbial attack, avionic equipment is susceptible to insect and animal damage which can result in corrosion.

(b) *Bacteria.* Bacteria may be either aerobic or anaerobic. Aerobic bacteria require oxygen to live. Oxygen can accelerate a corrosion atmosphere by oxidizing sulfur to produce sulfuric acid or by oxidizing ammonia to produce nitric acid. Bacteria living adjacent to metals will promote corrosion by deleting the oxygen supply or by releasing metabolic products. Anaerobic bacteria, on the other hand, can survive only when free oxygen is not present. The metabolism of these bacteria requires them to obtain part of their sustenance by oxidizing inorganic compounds such as iron, sulfur, hydrogen, and nitrogen. The resultant chemical reaction causes corrosion. Because of the acidic nature of bacterial microorganisms, metals are susceptible to microbial attack. Minor surface contamination can be accelerated into a major corrosion problem by local bacterial corrosion cells, or by additional acids liberated by the bacteria.

(c) *Fungus.* Fungus is a microorganism growth that feeds on organic materials and generally takes the form of molds, rusts, mildews, and smuts. Fungal growth requires specific environments and nutrients for survival. Fungi are commonly found in the following colors:

Black
Yellow
Green
Blue-Green

(d) *Fungi-Producing Environments.* While low humidity does not kill the fungi microbes, it slows their growth. Ideal growth conditions for most fungi microbes are temperatures between 68°F (20°C) and 104°F (40°C) and a relative humidity between 85 and 100 percent. It was formerly thought that fungal attack could be prevented by applying moisture-proof coatings to nutrient material or by drying the interior of compartments with desiccants. It is now known that some microorganisms remain in spore form for long periods, even under extremely dry conditions. Furthermore, electrical insulating varnishes and some moisture-proofing coatings are attacked by mold, bacteria, or other microbes, especially if the surfaces on which they are used are contaminated. Dirt, dust and other airborne contaminants are the least recognized contributors to microbial attack. Even small amounts of airborne debris can be sufficient to promote fungal growth.

(e) *Fungi Nutrients.* It has long been thought that materials such as wool, cotton, rope, feather, and leather were the only materials known to provide sustenance for fungi microbes. The increasing complexity of synthetic material makes it difficult or impossible to determine from the name alone whether a material will support the growth of fungus. Many otherwise resistant synthetics are rendered susceptible for fungi attack by the application of a plasticizer or hardener. The service life, size, shape, surface smoothness, and cleanliness of the equipment, its environment, and the type of fungi microorganism involved all determine the degree of fungal attack.

(f) *Damage.* Damage resulting from microbial attack can occur when any of three basic mechanisms or a combination of mechanisms is brought into play: Fungi are damp and have a tendency to hold moisture, which contributes to other forms of corrosion; because fungi are living organisms, they need food to survive. The food is obtained from the material on which the fungi are growing; these microorganisms secrete corrosive fluids that attack many materials, including some that are not fungi nutrient. Optical devices can also be damaged by microorganisms. Lens coatings are extremely susceptible to fungal attack which will take any of three forms: A spiderweb, a flat starfish shape which leaves a milky stain, or minute circular spots that etch the glass. Under proper atmospheric conditions, fungi can grow on almost any surface. (see Fig.4).

(g) *Corrosion Caused by Insects and Animals.* Damage to avionics equipment can be caused by small insects and animals, expecially in tropical environments. Equipment in storage is most susceptible to this type of attack, since insects and small animals may enter through vent holes or tears in packaging. In some cases insects have entered small openings, pitot lines and air vents in aircraft causing blockage. In the case of packaged equipment, they may build nests which tend to absorb moisture. This moisture, plus excretions and salts from the insects and animals, can cause corrosion and deterioration that goes unnoticed until the equipment or system is put to use and fails. Another type of damage can occur when electrical insulation, varnishes, and circuit board coatings become food for insects. Once bare wires or circuit components are exposed, more areas become available for corrosion and shorting to occur. See Table 3.

d. **Design, Packaging and Location of Avionics in Aircraft.** Prime contractor aircraft manufacturers allocate space inside aircraft for avionics equipment, and procure avionics from subcontractors. The subcontractor designs the equipment to meet allocated space and performance standards provided by the prime contractor. The equipment may require vented cooling or the equipment may be placed in the aircraft in an area susceptible to water leaks through airframes, resulting in water intrusion and equipment failure.

(1) **Requirement.** Each unit of avionics equipment must be designed to stand on its own in the operating environment and to be resistant to water intrusion, moisture, EMI and corrosion.

(a) Lids should be shoe box type.

(b) Fasteners should be located in vertical walls of the box vice on the lid.

(c) Cooling and venting should be designed to ensure that water cannot enter through cooling or venting duct holes.

(d) Cables connecting system to boxes must have drip loops.

(e) Avionics manufactures must get feedback information on reliability of equipment.

(f) Electrical connectors must be protected from the environment.

4. Lessons of the foregoing short history and findings of the assessment have been applied and have resulted in the development of a very successful avionics and electrical corrosion prevention and control program being conducted throughout the US Fleet.

5. We will now go through a standard maintenance cycle of a failed component. A failed component is removed from the aircraft and inducted into the second level of maintenance, the Aircraft Intermediate Maintenance Department (AIMD), to determine and correct the problem in the failed equipment. The equipment is opened and visually inspected for corrosion or contaminates. If corrosion is detected, the equipment is forwarded to the cleaning and corrosion work centers or shops. The equipment is disassembled by a trained technician. The corrosion is removed by miniature grinding tools, simple eraser, miniature grit blaster (Fig.5), or hand polisher. The mildest method is always used. General cleaning: The components are made ready to ensure water or cleaning agent does not damage interal components, (see Table 4.1 and 4.2). The component is then water washed, using a detergent water mix of nine parts water to one part detergent. Detergents used are under MIL-specification MIL-D-16791 (nonionic) or MIL-C-43616 with 16-1 mix, with a PH under 10. The clean components are then placed in a drying oven and dried at 130°F (54°C) where the drying time is dependent on the complexity of the equipment or component being dried — normally 3 to 4 hours are required. A hot air gun may also be used for spot drying. Table 5 contains basic avionics cleaning requirements, a list of cleaning chemicals, recommended cleaning process, and cleaning and drying restrictions.

a. Some component boxes, chassis, metal component may be cleaned using the ultrasonic cleaning method with solvent, i.e. Trichortrifluoroethane MIL-C-81302. Care must be taken not to expose the technician to this material as the material will remove oils from the body exposed to a solvent vapor and displaces oxygen. This material should always be used in small amounts in a well ventilated area. Face shield, rubber gloves and coveralls should be used when ultrasonic cleaning is conducted. An advantage to ultrasonic cleaning is drying time which is reduced to between 15 seconds and 3 minutes. A disadvantage to ultrasonic cleaning is that some frequencies in the cleaning unit can damage some circuits and components. Therefore components to be ultrasonically cleaned must be identified by engineering authority.

b. Hand cleaning with MIL-C-81302 can be accomplished by using a soft bristle brush.

c. When the equipment has been cleaned and any corrosion discovered has been removed and arrested the equipment is returned to the repair and check technician. The equipment is repaired and tested if required and corrosion prevention compound MIL-C-81309 type 3 class 2 aerosol is applied to internal areas of the equipment (see Fig.6 and Table 5). The material is spread on and the excess is wiped off leaving a thin nonconductive film of water displacing corrosion preventive compound. If contact points are involved points must be wiped to ensure nonconductive film is removed. The equipment is then closed and sealing materials are used as required to ensure water or corrosive fluids of any form can not enter the box. Three basic sealants are used meeting MIL-specific MIL-S-8802, MIL-S-81733 or room temperature vulcanizing (RTV) MIL-A-46146. Normally sealed areas are lids around fasteners and connector ports. The Ready for Issue (RFI) componment is then packaged and returned to the user or held in a store room until needed. (See Fig.7 and Table 6).

d. The first maintenance level (squadron) receives the RFI component and begins installing the component in the aircraft. The technician opens the access panel and inspects the area in whicht the component is to be installed (usually in a shock mounted rack) to ensure the area and shock mounted rack are clean and free from corrosion or contaminates. When satisfied the area is clean, the component is installed. The technician then inspects and hand cleans the electrical connector. The female connector is treated using MIL-C-81302 and a soft bristle brush after cleaning. MIL-C-81309 Type 3 Class 1 avionics grade water displacing corrosion prevention compound is applied to the female connector and the excess is wiped off and the connector is connected to the component. The component is then tested using aircraft power to complete the installation.

6. Electrical connectors: Electrical connectors have historically been prone to corrosion problems, as discussed in reference (1). However, since the avionics corrosion prevention and control program has been implemented, the problems are disappearing. Periodic maintenance is conducted on all aircraft connectors ranging from daily to 180 days or longer in some installations. Maintenance of connectors consists of keeping the connectors clean and dry, free from corrosion internally and externally. This is accomplished as follows:

a. Connectors Directly Exposed to the Environment. The connector is opened and inspected if corrosion is detected on pins or body of the connector, it is removed by the mildest method possible. The connector is then inspected with a 10X glass to ensure all corrosion product has been removed; the connector is then cleaned using an acid brush and MIL-C-81302. The female end of the connector is sprayed with MIL-C-81309 Type 3 Class 2 water displacing corrosion prevention compound; the excess is wiped off. It is reconnected and wiped off with a clean rag wet with MIL-C-81302 to remove body oils, fingerprints, etc. The external area of the closed connector is spread with MIL-C-85054 AMLGARD. The AMLGARD is

allowed to dry 30 minutes and a second coat is applied. In extreme cases the connector is wrapped with electrical insulating tape painted with RTV 3140. (See Fig.7.)

b. Test connector treated in this manner has been exposed on aircraft carriers for as long as 18 months with no degradation to the connector (see Fig.8).

7. Connectors internal to the aircraft are cleaned in the same manner as described above for the external connector. With MIL-C-81309 Type 3 Class 2 applied inside the connector frequency of preventative maintenance is dictated by operating environment.

a. Additional connector maintenance — sealing: Sealing the back shell of multi pin environmental connectors becomes necessary under some conditions, i.e., when side loads are applied to pins, when wetting agents are used in the connector back shell areas. When these conditions exist, the back shell of the connector is sealed as follows: The retainer ring and backshell are loosened and slid up the wire bundle exposing the rubber grommet containing wire receptacles.

b. The area of the rubber grommet is cleaned using an acid brush and MIL-C-81302, verifying that sealing plugs (dog bones) are installed in unused wire receptacle cavities. Sealant is applied (RTV-3140 alcohol cure), to the back side of the rubber grommet, working the nozzle of the applicator through the wire bundle to ensure complete coverage (see Fig.7). Sealant thickness should not exceed 1/16" (1.59 mm). Additional sealant may be added. However, at no time shall sealant exceed 1/8" (3.2 mm) thickness. Position connector face parallel to the floor/deck for 30 minutes for initial cure of sealant. After 30 minutes, the connector may be reconnected; however, the sealant will require 24 hours for complete cure.

8. When this procedure was developed RTV-118, which is an acetic acid cure material, was selected because it is clear, allowing the electronic technician to read pin numbers on the sealed back of the grommet. Wires can be changed with sealant in place using standard tools. When a wire is replaced a drop of sealant is placed in the area where work is accomplished. RTV-118 has been replaced with clear RTV-3140 which is a clear alcohol cure material eliminating the corrosive acetic acid. RTV-118 can be used, but time for a full 24 cure must be used to which requires connector to remain open preventing corrosion caused by gas off of the acetic acid. The only acetic acid cure material in use is RTV-730 which is a white high temperature material with a working temperature of 550°—600°F (287°—315°C). Use of RTV-730 must be authorized by engineering authority.

9. EMI Bonding Corrosion: Over the past 20 years, the electronic world has made tremendous advances in technology. In the development of low power microelectronic systems, the new equipment is light in weight, small in size, ideal for use in aircraft where weight and size are factors. The new systems are generally very dependable and are replacing the more cumbersome mechanical systems used in today's and earlier aircraft, i.e., fly by wire, autopilots, weapons control systems, etc. However, the new low power microelectronic equipment and systems are susceptible to electromagnetic interference (EMI) caused by high power electronic/electrical sources external to the affected system or equipment, resulting in system/equipment malfunction. To prevent EMI problems, the equipment/systems are shielded and grounded by bonding to the aircraft. Most of the materials selected for bonding by the electronic engineers have been good conductors of electricity but are cathodic to the aluminum substrate they are attached to, causing galvanic cells to be formed, resulting in corrosion (see Fig.9).

Facts

a. Corrosion of the airframe is caused by bonding material.

b. Airframe corrosion requires correction or structural repair.

c. Bond is lost, making the bonded equipment and system susceptible to EMI as bond cannot be maintained due to corrosion product.

d. EMI protection systems are required to ensure operation of modern microelectronic systems.

Some bonding systems that have been used:

a. Berrylium copper strips (see Fig.9).

b. Silver filled epoxy bonding material which is hydroscopic.

c. Aluminum to steel, etc. (see Fig.10).

d. Silver loaded silicon rubber EMI seals.

Action needed:

a. Development of EMI protective systems/materials that will provide required protection that will not cause corrosion in the operating environment.

b. Development of electronic systems that will stand on their own in an EMI environment.

10. The US Navy is investigating a and b above to determine the best, most economical method to provide required protection to electronic systems and stop the corrosion from occurring.

As stated above, this successful program is established throughout the US naval aviation community. It was established in accordance with Chief of Naval Operations (CNO) Instructions 4790.2C and amplified by COMNAVAIRLANT/COMNAVAIRPAC instructions. Technical information is provided in the Avionics Cleaning and Corrosion Prevention/Control Manual NAVAIR 16-1-540. Training is provided to supervisors and electronic technicians and mechanics by Naval Air Maintenance Training Detachment (NAMTRADET), Naval Air Rework Facilities

(NAVAIREWORKFAC) and on-site Naval Aviation Engineering Service Units (NAESU). Detailed requirements for AIMD and operational squadrons are contained in COMNAVAIRLANT/COMNAVAIRPAC instructions as follows.

a. Each activity shall establish an avionics cleaning and corrosion prevention/control program that will function on a day to day basis.

b. Avionics corrosion team members shall receive NAMTRADET training before they are considered qualified.

c. Avvionics Office shall have NAMTRADET training.

d. Establish an avionics equipment emergency reclamation team in each fleet activity. Emergency reclamation shall consist of electronic technicians who are trained to recover avionics equipment that have been explosed to unusually severe corrosive condition e.g., salt water immersion, fire extinguishing agents, battery acid, etc.

11. In order to ensure future designs for avionics components are more corrosion resistant, the Chief of Navy Material has issued guidelines for prevention and control of avionics corrosion (NAVMAT P 4855-2 dated June 1983). This document was developed and made available to industry.

12. Conclusion

a. Avionics corrosion damage can be minimized on aircraft and other military equipment by a dynamic corrosion prevention/control program.

b. Detailed training of involved personnel must be provided.

c. As new material becomes available the occurrence of avionics corrosion can be reduced through designing boxes that will not leak and material selection, i.e., non-corrosive materials for construction of component/equipment. (See Fig.11.)

d. Close cooperation between all facets i.e. the avionics/aerospace community, is needed to insure that the most durable, reliable avionics/electronics are provided to the armed forces.

REFERENCES

(1) G.T.Browne — COMNAVAIRLANT US Fleet Aircraft Corrosion AGARD CP-315 1981.

(2) — US Naval Air Systems Command Avionics Cleaning and Corrosion Prevention/Control Manual N/A 16-1-540.

(3) Irving S.Shaffer — NAVAIRDEVCEN Warminster PA Corrosion in Naval Aircraft Electronic Systems AGARD CP 315 1981.

Table 1: Corrosion of Metals — Nature and Appearance of Corrosion

Alloy	Type of attack to which alloy is susceptible	Appearance of corrosion product
Aluminum Alloy	Surface, pitting and intergranular.	White or gray powder.
Titanium Alloy	Highly corrosion resistant. Extended or repeated contact with chlorinated solvents may result in embrittlement. Cadmium plated tools can cause embrittlement of titanium.	No visible corrosion products.
Magnesium Alloy	Highly susceptible to pitting.	White powder snowlike mounds, and white spots on surface.
Carbon and Low Alloy Steel (1000—8000 series)	Surface oxidation and pitting, surface and intergranular.	Reddish-brown oxide (rust).
Stainless Steel (300—400 series)	Intergranular corrosion. Some tendency to pitting in marine environment (300 series more corrosion resistant than 400 series)	Corrosion evidenced by rough surface; sometimes by red, brown or black stain.
Nickel-Base Alloy (Incenel)	Generally has good corrosion-resistant qualities. Sometimes susceptible to pitting.	Green powdery deposit.
Copper-Base Alloy (Inconel)	Surface and intergranular corrosion.	Blue or blue-green powder deposit.
Cadmium (used as a protective plating for steel)	Good corrosion resistance. Will cause embrittlement if not properly applied.	White, powdery corrosion products.
Chromium (used as a wear-resistant plating for steels)	Subject to pitting in chloride enviroments.	Chromium being cathodic to steel, does not corrode itself, but promotes rusting of steel where pits occur in the coating.
Silver	Will tarnish in presence of sulfur.	Brown to black film.
Cold	Highly corrosion resistant.	Deposits cause darkening of reflective surfaces.
Tin	Subject to whisker growth.	Whisker-like deposits.

Table 2: Effects of Moisture and Fungi on Various Materials

Part or Material	Effect of Moisture and Fungi
FIBER: Washers, supports, etc.	Moisture causes swelling which causes the support to misalign, resulting in binding of support parts. Destroyed by fungi.
FIBER: Terminal strips and insulators.	Electrical leakage paths are formed, causing flashovers and crosstalk. Insulating properties are lost. Destroyed by fungi.
LAMINATED PLASTICS: Terminal strips and boards, switchboard panels, etc., tube sockets and coil forms and connectors.	Insulating properties are lost. Leakage paths cause flashovers and crosstalk. Delamination occurs and fungi grow on surface and around edges. Expansion and contraction under extreme temperature changes.
MOLDED PLASTICS: Terminal boards, switchboards panels, connector, etc., tube sockets and coil forms.	Machined, sawed or ground edges of surfaces and supporters of fungi, causing shorts and flashovers. Fungi growth reduces resistance between parts mounted on plastic to such an extent that the parts are useless.
COTTON LINEN, PAPER AND CELLULOSE DERIVATIVES: Insulation, coverings, webbing, belting, laminating dielectrics, etc.	Insulating and dielectric properties are lost or impaired, causing arcing, flashovers and crosstalk. Destroyed by fungi.
WOOD: Cases, houses and housings, plastic fillers, masts, etc.	Dry rot, swelling and delamination caused by moisture and fungi.
LEATHER: Straps, cases, gaskets, etc.	Moisture and fungi destroying tanning and protective materials, causing deterioration.
GLASS: Lenses, windows, etc.	Fungi grow on organic dust, insect track, insect feces, dead insects, etc. Dead mites and fungi growth on glass obscure visibility and corrode nearby metal parts.
WAX: For impregnation.	Fungi-inhibiting waxes which are not clean support the growth of fungi, cause destruction of insulating and protective qualities, and permit entrance of moisture which destroys parts and unbalances electrical circuits.
METALS:	High temperature and moisture vapor cause rapid corrosion. Fungus and bacterial growth produce acid and other products which speed corrosion, etching of surfaces and oxidation. This interferes with the operation of moving parts, screws, etc., and causes dust between terminals, capacitors, plates or air condensers, etc., which in turn causes noise, loss in sensitivity and arc-overs.
METALS, DISSIMILAR:	Metals may have different potentials. When moisture is present, one of the metals (anode) corrodes.
SOLDERED JOINTS:	Residual soldering flux on terminal boards holds moisture, which speeds up corrosion and growth of fungi. Soldering iron should not come in contact with wire insulation.

Table 3: Effects of Corrosion on Avionic Equipment

Component	Failure Mode
Antenna Systems	Shorts or changes in circuit constants and structural deterioration.
Chassis, Housings, Covers and Mount Frames	Contamination, pitting, loss of finish and structural deterioration.
Shock Mounts and Supports	Deterioration and loss of shock effectiveness.
Control Box Mechanical and Electrical Tuning Linkage and Motor Contacts	Intermittent operation and faulty frequency selection.
Water Traps	Structural deterioration.
Relay and Switching Systems	Mechanical failure, shorts, intermittent operation and signal loss.
Plugs, Connectors, Jacks and Receptables	Shorts, increased resistance, intermittent operation and reduced system reliability.
Multi-Pin Cable Connectors	Shorts, increased resistance, intermittent operation and water seal deterioration.
Power Cables	Disintegration of insulation, and wire/connector deterioration.
Display Lamps and Wing Lights	Intermittent operation, mechanical and electrical failures.
Waveguides	Loss of integrity against moisture, pitting, reduction of efficiency and structural deterioration.
Radar Plumbing Joints	Failure of gaskets, pitting and power loss.
Printed Circuits and Microminiature Circuits	Shorts, increased resistance, component and system failures.
Batteries	High resistance at terminals, failure of electrical contact points and structural deterioration of mounting.
Bus Bars	Structural and electrical failures.
Coaxial Lines	Impedance fluctuations, loss of signals and structural deterioration of connectors.

Table 4.1: Basic Avionics Cleaning Requirements

Always use the Mildest Cleaning Method

1. Pre-Cleaning:
    a. Disconnect power supply
    b. Ensure all drain holes are open
    c. Remove covers, etc.
    d. Disassemble where practical
    e. USE ONLY AUTHORISED MATERIALS
    f. Assure compatibility of material before use
    g. Mask, protect accessories, components to prevent entrance of water, solvent/cleaning component
2. Cleaning equipment hand cleaning tools for hand cleaning:
    a. Cotton lint free cloth
    b. Cheesecloth
    c. Cotton tip applicators (Q tips)
    d. Acid Brush
    e. Toothbrush
3. Cleaning equipment installed/materials:
    a. Spray cleaning booth
        (1) Water
        (2) Water detergent
        (3) Solvent
    b. Ultrasonic
        (1) Aqueous
        (2) Chemical

Table 4.2: Avionic Cleaning Material

Description	Characteristics	Application	Restrictions
Cleaning Compound, Aircraft Surface, MIL-C-43616, Class 1, or Class 1A* or equivalent	General cleaning agent for light soil and dirt in equipment bays, on external cases and covers, and antenna assemblies	Mix one part cleaner in 16 parts water and apply with Cleaning Cloth. Rinse with fresh water and wipe dry.	Do not use around oxygen, oxygen fittings, or oxygen regulators since fire or explosion may result.
	Heavy concentration of surface grime, oil, exhaust smudge and fire extinguishing chemicals in equipment bays and on external cases and covers.	Mix one part cleaner in 9 parts water and apply with Cleaning Cloth. Rinse with fresh water and wipe dry. Cotton cloth.	Never use full strength nor ever allow to dry on surface. Refer to Section IX for emergency cleaning procedures after immersion or exposure to gross amounts of salt water, fire extinguishing chemicals soot, smoke or vaporous gases.
Detergent, Liquid Nonionic MIL-D-16791, Type I	Cleaning of transparent and acrylic plastics and cockpit indicator glass covers. Also used in the water-based Solvent Spray Cleaning Booth and the Aqueous Ultrasonic Cleaner for removing contaminants.	For hand cleaning, apply with Flannel. Let dry, then remove with dry flannel cloth. Cloth.	Mix 1 fluid oz. per gal. water.

WARNING

Solvents are flammable and solvent vapors are toxic. Keep solvents away from open flames and use only in a well-ventilated area. Avoid solvent contact with skin.

Description	Characteristics	Application	Restrictions
Cleaning and Lubricating Compound, Electrical Contact, MIL-C-83360, Type I	A cleaner-lubricant compatible with potting compounds, rubbers and insulations. Contains 3 to 5 percent silicone. May be used for cleaning and lubricating electrical contacts.	Apply by spraying an even film to the surface. Wipe clean with Disposable Applicator, or Pipe Cleaner.	Do not use as a substitute for MIL-C-81302 Type I or Type II. Avoid application to area requiring soldering or coating.
Cleaning Compound, Solvent Trichlorotri-fluoroethane, MIL-C-81302, Type I (Ultra-Clean)	General cleaner for light to medium surface dust, dirt and contaminants on precision equipment, instruments, etc., where ultra-clean solvent is required. Use in cleanroom applications. May be used to clean dirt and dust from areas where critical soldering is required.	Apply by wiping or scrubbing on affected area with Acid Brush or Toothbrush. Air dry or oven dry, as applicable.	Do not use on acrylic plastics and acrylic conformal coatings. Do not use on unsealed aluminum electrolytic capacitors. Damage may result to end caps and cause leakage.
Cleaning Compounds, Solvent Trichlorotri-MIL-C.81302, Type II	General cleaner for light to medium surface dust, dirt and contaminants on all internal areas of avionic equipment. May be used to clean dirt and dust from areas where soldering is required.	Same as above.	Same as above.

* Aerosol can be used as packaged without additional dilution.

Description	Characteristics	Application	Restrictions
Dry cleaning Solvent, P-D-680, Type II (High Flash Point)	General purpose cleaner for medium to heavy dirt, dust, contaminants and fire extinguishing chemicals in equipment bays and on external cases, covers structural hardware, mounts, racks, etc.	Apply by wiping or scrubbing affected area with Cleaning Cloth, Cheesecloth or Brush, Typewriter, as appropriate. Wipe clean with Cleaning Cloth.	Do not use around oxygen, or oxygen fittings, or oxygen regulator since fire or explosion may result.
	Cleaner for smoke damage removal on internal chassis components.	Apply by scrubbing affected area with Cleaning Cloth, Cotton, Toothbrush, or Brush, Typewriter, as appropriate. Wipe clean with Cleaning Cloth.	When used for smoke damage removal, always follow-up with solution of one part deionized water and one part Isopropyl Alcohol, TT-I-735.
	Cleaner for smoke damage removal on circuit components and laminated circuit boards.	Apply by wiping or scrubbing affected areas with Cleaning Cloth, Cotton or Toothbrush. Wipe clean with Cleaning Cloth.	May cause swelling of silicone rubber seals in equipment exposed to immersion for long periods.
	Cleaner for removal of Water-Displacing Corrosion Preventive Compounds, MIL-C-81309, Type III, MIL-C-81309, Type II, MIL-C-85054; and Corrosion Preventive Compound, MIL-C-16173, Grade 4.	Apply with Brush, or Toothbrush, as appropriate. Wipe clean with Cleaning Cloth, Cotton.	May soften some plastics, wire harness tubing, or plastic coating on wiring. Test affected area for adverse reactions prior to general application.
Isopropyl Alcohol, TT-I-735	General purpose cleaner and solvent for removal of salt residue and contaminants common to internal avionic equipment. General cleaner for internal chassis components.	Apply a solution of one part deionized or distilled water and one part Isopropyl Alcohol, TT-I-735, to the affected area with Cleaning Cloth or Toothbrush	Isopropyl Alcohol, TT-I-735, is highly flammable. All applications of Isopropyl Alcohol, TT-I-735, and water may be air dried or dried by portable air blower or ovens
	Solvent cleaner for solder flux residue in all applications of electronics, electrical equipment and microminiature circuits.	Apply a solution of one part deionized or distilled water to three parts Isopropyl Alcohol, TT-I-735 and scrub the solder joint and adjacent area with Acid Brush or Toothbrush. Wipe clean with Cleaning Cloth, Cotton.	
	Cleaner for fingerprint removal on metals and non-metallics.	Apply a solution of one part deionized or distilled water and one part Isopropyl Alcohol, TT-I-735, to affected area with Cleaning Cloth, Cotton. Wipe clean.	

Description	Characteristics	Application	Restrictions
	Cleaner for bacteria and fungi attack on all metals and non-metals.	Apply a solution of one part Solvent *Trichlorotrifluoroethane*, MIL-C-81302, Type II and one part Isopropyl Alcohol, TT-I-735, to affected area with Cleaning Cloth, Cotton. Wipe clean. Air dry.	
	Cleaner for salt-water immersion and fire extinguishing chemicals on all internal circuit boards.	Apply a solution of one part Isopropyl Alcohol, TT-I-735, and nine parts Solvent Trichlorotrifluoroethane, MIL-C-81302, Type II to affected area with Cleaning Cotton Cloth, Acid Brush or Toothbrush, as appropriate.	
	Cleaner for electrical contact surfaces.	Apply a solution of one part deionized or distilled water and one part Isopropyl Alcohol, TT-I-735, to affected area with Acid Brush or Pipe Cleaner. Wipe clean and air dry.	
Water, Distilled	Cleaner for solder flux residue in all applications of electronics, electrical equipment and microminiature circuits.	Apply a solution of one part deionized or distilled water to three parts Isopropyl Alcohol, TT-I-735 and scrub joint and adjacent area with Acid Brush or Toothbrush. Wipe clean with Cleaning Cotton Cloth.	Deionized water, obtainable from commercially available processing units that are plumbed into some shore activity shops, is an authorized substitute.

Table 5.1: Recommended Cleaning Process Versus Type of Avionic Equipment

Type Equipment	Aqueous Ultrasonics	Solvent Ultrasonics	Water Base Spray Booth	Abrasive Tool	Mini-Abrasive	Hand Clean
HOUSING/COVERS	X	X	X	X	X	X
CHASSIS	X	X	X	X	X	X
RACKS/MOUNTS	X	X	X	X	X	X
CONTROL BOXES	X	X(1)	X	X	X	X
INSTRUMENTS					X(1)	X
LIGHT ASSEMBLIES	X	X	X	X(1)	X	X
WAVEGUIDES	X	X	X	X(1)	X	X
WIRE HARNESSES			X		X	X
SERVOS/SYNCHROS					X(1)	X
ANTENNAS, BLADE	X	X	X		X	X
ANTENNAS, DOME	X(1)	X(1)	X	X(1)	X	X
ANTENNAS, RADAR			X	X(1)	X	X
ANTENNAS, ECM					X	X
MOTORS	X	X(1)	X	X(1)	X	X
GENERATORS	X	X(1)	X	X(1)	X	X
BATTERIES						X
CIRCUIT BREAKER PANELS	X	X	X		X	X
GYROSCOPES			X(1)		X(1)	X
PLUGS AND CONNECTORS			X		X	X
HIGH DENSITY CONNECTORS					X	X
EDGE CONNECTORS			X		X	X
COAXIAL CONNECTORS					X	X
PRINTED CIRCUIT BOARDS			X			X

Table 5.2: Cleaning and Drying Restrictions

Component	Problem	Solution
Transformers	Trap solution in housing	Seal
Synchros & Servos	Removes lubricant from bearing	Seal or Remove
Meters & Instrument Gauges	Trap solutions through open back	Seal
Sliding Attenuators (RF)	Trap solution in slide housing	Seal or Remove
Tunable Cavities	Trap solution in cavity area	Seal or Remove
Variable Attenuators (Microwave)	Trap solution in housing	Seal or Remove
Waveguide (Microwave)	Trap solution in guide housing (when installed)	Seal or Remove
Rotary Switches	Trap solution through open housing	Seal
Potentiometers	Trap solution through open housing	Seal
Delay Lines (Physical)	Trap solution in housing	Seal or Remove
Klystron Cavity	Trap solution in sockets	Remove tube and seal socket
Fan Motors	Trap solution in housing	Seal or Remove
Paper Capacitors	Disintegrate	Seal
Printed Circuit Board	Trap solution (when installed)	Remove (clean separately)
Vacuum Tubes	Shock damage	Remove
Sliding Cam Switches	Shock damage to cam	Remove or hand clean only
Crystal Detectors	Heat damage from oven	Dry at 130°F (54°C) maximum
APC Connectors (Microwave)	Shock damage to center conductor	Seal and hand clean only
Wire Wrap Connections	Shock damage	Hand clean only
Gyroscopes	Trap solution in housing	Seal

Table 6

Description	Characteristics	Application	Restrictions
Corrosion Preventive Compound, Water-Displacing, Ultra-Thin Film, Avionics Grade, MIL-C-81309, Type III	General preservative for internal areas of avionic equipment; internal areas of electrical connectors, plugs, receptacles; and solder joints. Contains water-displacing properties.	Apply by spraying an even, thin film to the surface.	Not intended for use on exterior surfaces of avionic equipment. Deposits a thin, nonconductive film which must be removed for proper function of contact points and other electromechanical devices where no slipping or wiping action is involved. Do not use around oxygen, oxygen fittings, or oxygen regulators, since fire or explosion may result. Can be removed with Dry Cleaning Solvent, P-D-680, Type II.
Corrosion Prevention Compound, Water-Displacing, Ultra-Thin Film, MIL-C-81309 Type II	General preservative for internal and external areas of chassis, equipment covers, hardware, mounting brackets, latches, hinges, terminal boards, bus bars, ground straps, and internal/external areas of junction boxes.	Apply by spraying an even, thin film to the surface.	Not intended for use in interior surfaces of electrical connectors, plugs, and receptacles. Do not use on interior surfaces of coaxial connectors. Deposits a thin, nonconductive film which must be removed for proper function of contact points and other electromechanical devices where no slipping or wiping action is involved. Do not use around oxygen, oxygen fittings, or oxygen regulators, since fire or explosion may result. Can be removed with Dry Cleaning Solvent, P-D-680, Type II.
Corrosion Preventive Compound, Water-Displacing, Clear MIL-C-85054	General preservative for external surfaces exposed to elements and moisture, including: chassis, equipment covers, hardware, mounting racks, equipment racks, shelving, brackets, radar plumbing, antenna hardware, latches, terminal boards, bus bars, ground straps, junction boxes, fasteners, and exterior surfaces of electrical connectors, coaxial connectors, plugs and receptacles.	Apply by spraying an even, thin film or brushing onto the surface. Material presents a thin, non-tacky, clear film.	Not intended for use on interior surfaces of avionic equipment. Do not use on interior surfaces of electrical connectors, coaxial connectors, plugs, or receptacles. Do not use around oxygen, oxygen fittings, or oxygen regulators, since fire or explosion may result. Can be removed with Dry Cleaning Solvent, P-D-680, Type II or Isopropyl Alcohol, TT-I-735.

Table 6 (Continued)

Description	Characteristics	Application	Restrictions
Corrosion Prevention Compound, Solvent Cutback, Cold-Application MIL-C-16173 Grade	General preservative for external surfaces exposed to elements and moisture, including: mounting racks, shelving, brackets, radar plumbing, shock mounts, rigid mounts, antenna hardware, general hardware, hinges fasteners, ground straps; and exterior surfaces of electrical connectors, coaxial connectors, plugs and receptacles.	Apply by brush or spraying an even thin film to the surface. Material presents a semi-transparent film.	Not intended for use on interior surfaces of avionic equipment. Do not use around oxygen, oxygen fittings, or oxygen regulators, since fire or explosion may result. Can be removed with Dry Cleaning Solvent, P-D-680, Type II. Must be applied over Water-Displacing Corrosion Preventive Compound, MIL-C-81309, Type II, to accomplish a complete "water-displacing and preservative system" on all areas exposed to elements and moisture.

Fig.1 Uniform surface attack on a connector

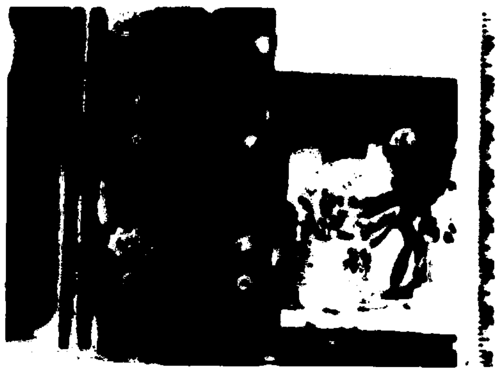

Fig.2 Galvanic corrosion of a wire connection

Fig.3 Pitting and general attack of circuit board and connections

Fig.4 Fungus growth on electronic circuit board

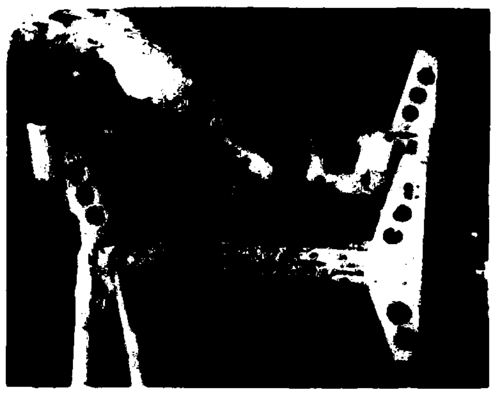

Fig.5 Miniature grit blast cleaning of circuit board

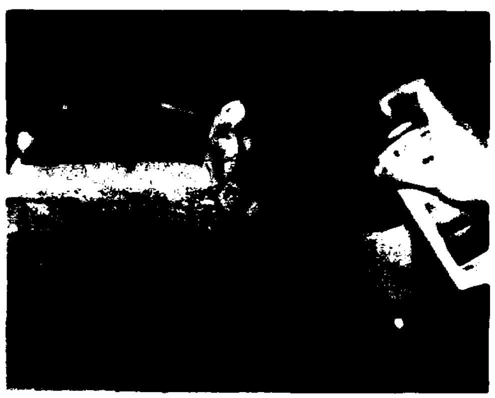

Fig.6 Corrosion resistant primer coating being applied to avionics enclosure

Fig.7 Application of RTV sealant to an electrical connector

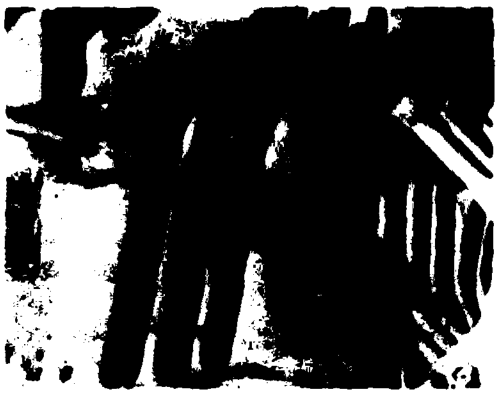

Fig.8 Electrical connector exposed on carrier based aircraft for over 18 months

Fig.9 Corrosion adjacent to beryllium copper EMI strips

Fig.10 Disimilar (aluminum to steel) connector showing galvanic corrosion

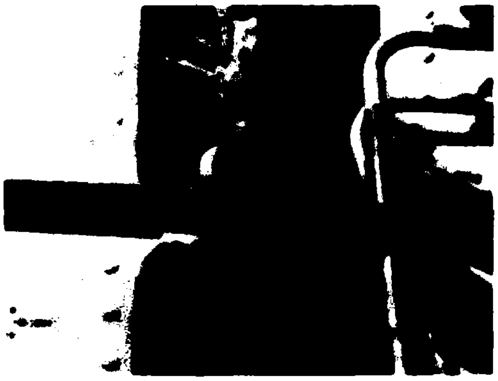

Fig.11 New non-metallic electrical connector shell shows no corrosion after extended exposure to the carrier environment

AD-P005 753

CORROSION IN AVIONICS AND ASSOCIATED EQUIPMENT: CAUSE, EFFECT AND PREVENTION

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SUMMARY

This paper addresses, with examples, the cause, effect and prevention of corrosion as it relates to Canadian Forces aircraft. It deals particularly with aircraft operated in a marine environment and is based on the experiences of the authors during previous service with the Department of National Defence and in their present employment in industry. The Canadian Forces corrosion prevention treatment program is also mentioned, and we have taken the liberty to discuss it briefly.

INTRODUCTION

1. The purposes of this paper are threefold as follows:

a) to stimulate thought and discussion on the subject;

b) to enhance the understanding of the subject by readers; and

c) to promote activity into research and development of corrosion-resistant avionics, as well as implementation of maintenance oriented corrosion prevention and treatment programs.

At present in the Canadian Forces, there is considerable effort expended in the prevention, detection and treatment of corrosion; however it is mainly focused on aero-engine and airframe areas with little attention paid to avionics, until component failure results.

HISTORY

2. The first avionics corrosion was likely recorded in an aircraft log set as a green deposit forming on copper or brass terminal lugs. This was commonly called verdigris or green rust. The treatment was vigourous application of a wire brush and the preventative maintenance was the application of copious quantities of petroleum jelly, also known as vaseline. Incidentally, the same methods also applied to the terminals of lead-acid batteries commonly used during that era.

3. It is hoped that readers will bear with the above tongue-in-check approach to the subject since it is intended to draw attention to the dearth of historical data related to the subject of corrosion in avionics. It is only in hindsight that one who has been involved in avionics maintenance for over thirty years realizes the number of incorrect procedures which were common practice. An example of this is solder flux corrosion which can result from the use of activated resin core solder as well as acid or inorganic chloride flux core solders. While it has long been recognized that the latter should not be used in aircraft, it was only recently that the former was officially recognized as a source of corrosion and clearly identified in both NAVAIR 16-1-540 and NAVAIR 01-1A-505 as inappropriate for use in avionics equipment.

4. The Canadian Forces did not have a structured corrosion control program in place until the early 1960s when significant corrosion damage was found on Grumman CS2F "Tracker" ASW aircraft. This was mainly airframe related but did result in a more in-depth inspection and a program called "TRACRAP" (Tracker Corrosion Removal and Prevention). This program entailed removal of all avionic black boxes, which were routed to shops for inspection and cleaning, thorough inspection of the aircraft, corrosion removal and treatment, thorough washing of the aircraft and application of WD-40 to all areas. This program proved highly successful and was continued until the Royal Canadian Navy (R.C.N.) decommissioned their only carrier, H.M.C.S. Bonaventure.

5. During this same time frame the Sea King Helicopter (orginally designated in Canada as CHSS-2, now CH124A) was acquired and introduced into the fleet as an A.S.W. platform, initially flying from the carrier and eventually from Destroyer Escorts (DDH). The operational environment - sonar dipping at 40 feet altitude - resulted in the ingress of significant amounts of salt laden air to the cockpit and cabin area. In addition, the flight deck of the DDH is relatively close to the ocean surface and is therefore subject to salt spray and the occasional wave. All of the above factors contributed to an increase in corrosion in the fleet, a resultant increase in corrosion related defects and aircraft down time. In order to address this problem, reduce corrosion defects and to increase operational availability, several positive steps were taken:

a) Training in corrosion control, detection, treatment and prevention was added to the various training curriculums for maintenance personnel;

b) A corrosion control kit was developed and issued;

c) Information was developed or adopted and disseminated in the form of technical orders; and

d) A Corrosion Control Program of preventative maintenance was initiated in all shipborne detachments of helicopters. Aircraft deployed at sea or operating over the sea were thoroughly washed with fresh water at the end of each day's flying operations. The helicopter was divided into areas so that an area could be thoroughly inspected, cleaned and treated as necessary and the entire aircraft was thus completely inspected and treated once a week. Products such as AMLGUARD, LPS-1, LPS-3 and WD-40 were specified for applicable use. The results were positive but not spectacular. Corrosion was reduced and damage minimized, however improvements were restricted to airframe and engine areas. Avionics corrosion prevention was limited to spraying LPS-1 on connectors or the liberal application of DC-4 silicon on external power receptacles. This, unfortunately, is still very much the situation as it stands today.

EXAMPLES

6. The Canadian Forces has, in recent years, adopted a policy of maintenance as necessary. That is, "if it works don't fix it." As a result, many of the components in the aircraft are never removed unless they fail. They are inspected in-situ and perhaps given a perfunctory cleaning. The following illustrations of instruments, taken from a CH-124A Sea King Helicopter at the IMP facility, provide examples of the result. The instrument panel was originally manufactured from magnesium. The instrument cases are either tinned copper or brass, protected by a matte black paint. The paint became chipped or worn on both instruments and the magnesium panel, and with the aid of salt laden air to provide the electrolyte, galvanic corrosion took place. The corrosive damage to the instrument appeared minimal as illustrated in Figure 1 (without magnification).

7. However when viewed under a 100X microscope, Figure 2, it can readily be seen that the integrity of the hermetically sealed case has been breeched. Similar comparison may be noted in Figures 3 and 4 as well as Figures 5 and 6. Incidentally all three of these instruments were removed from the same aircraft during Depot Level Inspection and Repair at IMP Group Ltd. Figures 7, 8 & 9 illustrate the extent of the corrosion on the instrument panel, while Figure 10 clearly shows corrosion visible to the naked eye on an instrument. As a result of these findings we are advised that the Canadian Forces is initiating action to have all instruments removed from the aircraft for inspection and treatment at every periodic inspection interval (400 flying hours).

8. Figure 11 illustrates the condition of a relay that has very likely never been removed from the aircraft since first installed 20 years ago. This relay was still electrically serviceable and functioning despite the severe external corrosion illustrated in Figures 12 and 13.

9. IMP Group has had some experience in salvaging aircraft which have been immersed in water, both salt and fresh. One such aircraft which had been safely landed in the North Sea, off the coast of Holland, and subsequently badly damaged in the salvage operation, was restored by IMP to flying condition. Several interesting lessons were learned from this experience. Although all the correct decontamination procedures were followed; ie: wash with fresh water, spray with WD-40 etc-etc, initial inspection of the aircraft on return to Canada revealed extensive corrosion of electrical component such as relays, circuit breakers, switches etc. No corrosion was initially found in the wiring, however, within a few weeks a white to green chalky corrosion was noted on the shielded wiring near the ends. It was decided that this could be removed by cutting off the corroded portion and re-terminating. It soon became evident, however, that the shielding acted as a wick and that corrosion was proceeding rapidly throughout the length of all shielded wire. This necessitated the complete replacement of all shielded wiring which had been subjected to salt water. A more recent experience involves the restoration of a Sea King Helicopter which crashed and turned turtle in a "fresh water" lake while practicing landings and takeoffs. The emphasis on the term "fresh water" is for a very good reason. Although the authors have not had the water from this lake analyzed it is apparent that there must be a high

acid content since the corrosion of components, particularly those which held some of the water for an extended period, was nearly as bad as if the aircraft had been submerged in salt water. This is clearly visible in Figures 14 and 15.

10. An unusual but interesting example of corrosion was found as an offshoot of this accident. Some of the avionic components of the aircraft, including the Automatic Stabiliza- tion Equipment (ASE) Amplifier, were salvaged, stripped, cleaned, treated and rebuilt. After a short period of operation they were found to exhibit signs of what appeared to be corrosion. This was evidenced by a white powdery substance on sharp corners of discrete components such as transformers, resistor leads, circuit board tracks, connectors and mounting hardware. Subsequent analysis and investigation revealed the corrosion products to be lead and tin salts of formic acid, basically reaction products of formic acid and solder (tin lead alloy).

11. The origin of the formic acid was initially a mystery. Suspicion at first focused on the conformal coating applied to circuit boards after assembly is complete. This coating material, an Epoxy Insulating Varnish, was subsequently tested and no evidence of formic acid was found. The investigation then focused on the cleaning solvents used in the ultra-sonic cleaner, Trichlorotrifluorethane (FREON TF), supposedly conforming to MIL-C-81302. The batch was quarantined and samples analyzed. This analysis proved that there were in fact contaminants which remained on the boards after cleaning and stayed dormant until the components heated up in operation. The contaminants then produced formic acid in gaseous form which bled through the conformal coating to settle on metallic components and produce the white powder as a by-product of corrosion. All of the components affected were recalled, stripped of conformal coating, recleaned ultra- sonically using the same type of solvent (different batch) and returned to service with no further problems.

DISCUSSION

12. As can be seen from the examples previously described, corrosion comes in many forms, from many sources, and is insidious in its attacks. There are a few metallic substances which exhibit resistance to corrosion, either through natural characteristics, ie. gold, or because of a treatment or process, ie. stainless steel. Even these materials have drawbacks as regards their use in the design of avionics equipment, either because of the softness in the former case or in poor conductivity in the latter.

13. Progress has been made in the design of avionics, both in the use of corrosion resistant materials, such as stainless steel connector shells for use in "SWAMP" areas and in better protection of components from the elements, and in particular, the ingress of moisture. For example, there is available a complete line of shrinkable connection devices such as splices, shield terminators and co-axial connectors which are easily installed and which completely seal out moisture. In addition, shrink fit encapsulation, boots and transitions in many forms are available and should be used in conjunction with corrosion resistant hardware in areas of aircraft which are exposed to the elements.

14. Our company is in the process of completely rewiring the Canadian Forces fleet of Sea King helicopters. We have taken full advantage of the many new products in the market to reduce the possibility of electrolyte being introduced to the many dissimilar metal "batteries" which exist throughout the aircraft.

15. Water displacing compounds which leave a moisture-proof skin over areas which are prone to corrosion are coming into more general use. For example a product available under MIL-C-85054 is being used by IMP to protect ground studs in the Sea King. After all ground wires are assembled to the stud and checked to ensure proper bonding, two coats of this material are applied, with a drying period in between. The result is a transparent waterproof seal which, if corrosion is detected through the transparency, is easily removed with a solvent for treatment of the corrosion. These same materials or similar, as discussed in previous papers presented to this committee, may be used to great advantage in protecting antennas and antenna co-axial connectors from corrosion which is prevalent by virtue of the location of many antennae in the hull of the vehicle.

CONCLUSIONS

16. Corrosion will be a major cause of aircraft and avionic equipment failure for the foreseeable future. We as engineers, scientists, designers, and/or maintainers can minimize the cause and effect of corrosion through development, design, application and education programs. Progress, however, can only be achieved through improved technology. Improved technology requires Research and Development (R&D) which must be funded. In order to attract R&D funding, it must be proven to fleet operators, either civilian or military that the cost is warranted. It follows, therefore, that we must be more effective in documenting the costs of avionics corrosion results in mission aborts or reduced capability, increased maintenance costs etc., etc, but until we can put a proven firm price on it the chances of attracting more R&D funding are slim.

Fig. 1 Instrument Bezel - note corrosion near numeral "5".

Fig. 2 Magnified view of corrosion from Fig. 1.

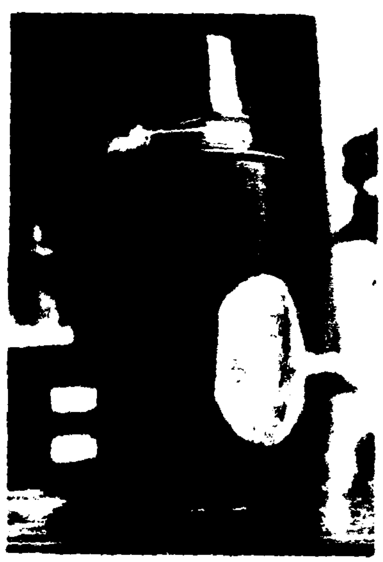

Fig. 3 Instrument corrosion as seen with naked eye.

Fig. 4 White area from Fig. 3 magnified to illustrate case integrity is breeched.

Fig. 5 Instrument case with corrosion apparent to naked eye.

Fig. 6 Area of corrosion in Fig. 5 magnified to illustrate case integrity is breeched.

Fig. 7 Instrument panel, Sea King Helicopter. Note white material evidence of salt water.

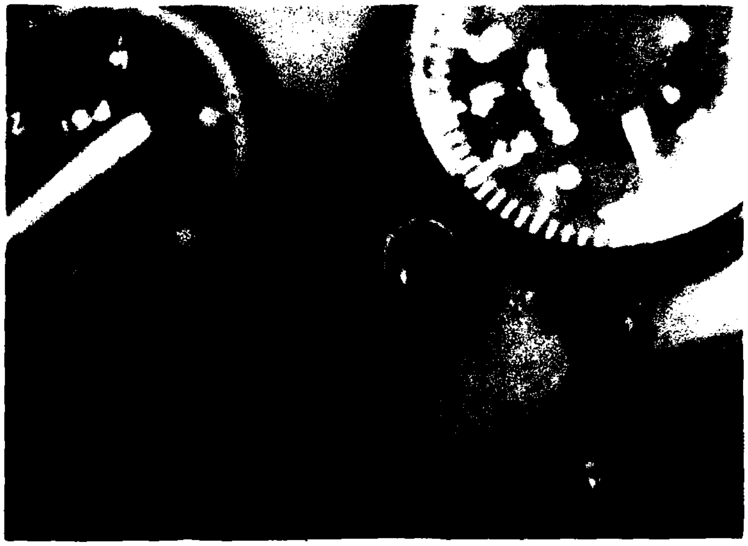

Fig. 8 Close up of instrument panel illustrating extent of corrosion on light socket.

Fig. 9 Magnesium instrument panel stripped of paint. Note extent of corrosion.

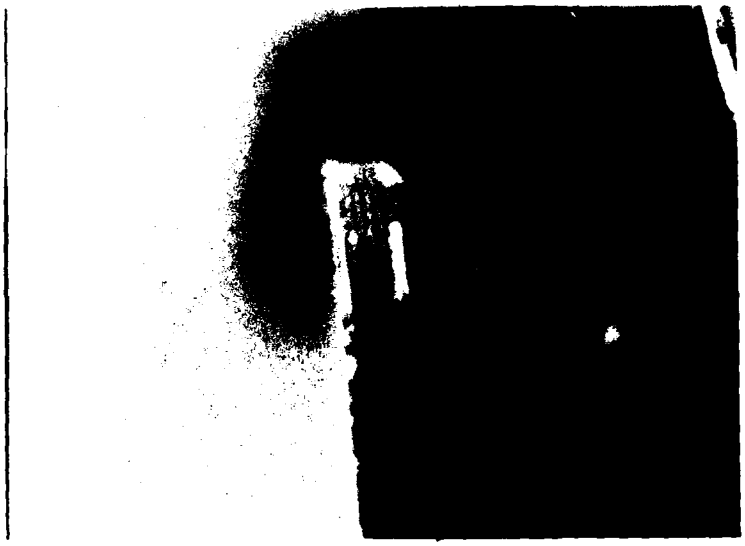

Fig. 10 Engine instrument corrosion.

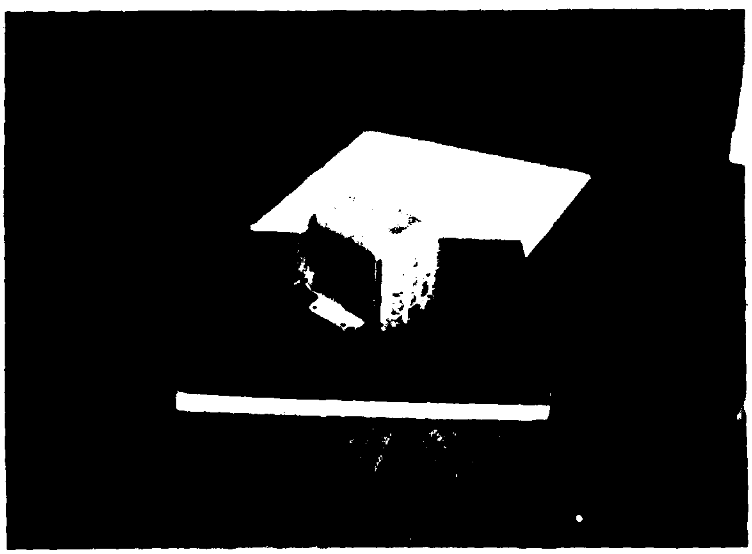

Fig. 11 Relay corrosion.

Fig. 12 Relay corrosion.

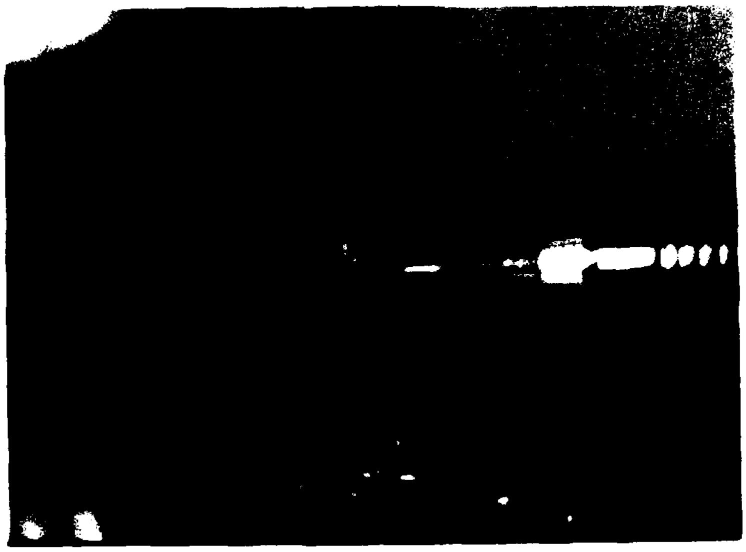

Fig. 13 Close up of corrosion on relay.

Fig. 14 Relay exhibiting corrosion resulting from "fresh" water immersion of a Sea King Helicopter.

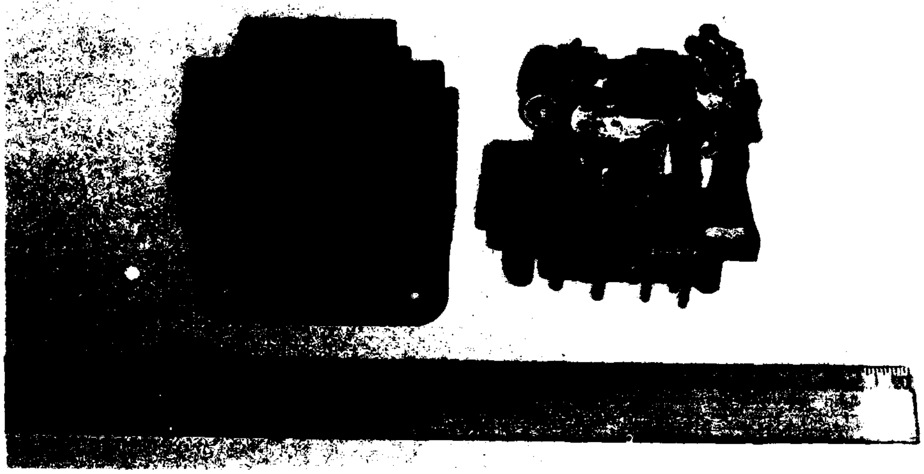

Fig. 15 Relay exhibiting corrosion resulting from "Fresh" water immersion of a Sea King Helicopter.

AD-P005 754

AVIONICS AND CORROSION

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ABSTRACT

Avionic manufacturing and environmental conditions generate corrosions and / or make easier the action of corrosion in various part of an avionic system. This paper deals with a brief survey of environmental conditions in the avionic field, how to reproduce them in accordance with norms and which associated problems could occur.

All parts of an avionic system are successively examined : housing box, printed circuit boards, hybrids and integrated circuits. For each part, examples and solutions are given.

1. INTRODUCTION

1.1 Equipment description

SAGEM avionic systems are airborne on various aircrafts. They intensively use, among others, the ULISS inertial navigation units.

A ULISS system is a lidded box housing a platform and a set of electronic modules. An electronic module is a two printed circuit board sandwich cemented on a metallic frame. Air forced between both printed circuit boards cools down the electronic.

50 to 150 electronic parts are laid out on each printed circuit board such as :

- integrated circuits, MSI, LSI, VLSI,
- thick and thin film hybrids,
- discrete components.

1.2 Avionic systems

Avionic systems undergo the most severe environmental conditions. So the joined action of tropical molds or fungii and humid heat causes coating varnish and paint corrosion. On aircraft carriers salt and humidity create stray electrolysis giving birth to corrosion when equipment is on. Airplanes themselves give off kerosene, motor oil and other products enabling corrosion to settle in.

In spite of anti-corrosion technics applied all along our system designs two corrosive attacks took place on our electronic modules. This paper deals with them both.

One has only a cosmetic effect on electronic modules and, so far, no failure can be related to it. The other one concerns integrated circuit realization. It is reponsible for a significant number of failures in the field.

We came up with solutions in both cases, which were successfuly applied. These attacks are directly related to electronic modules and their protection. Other kinds of corrosion exist that shorten the life expectancy of non-electronic parts on avionic systems.

They are :

- rubber corrosion,
- corrosion due to vibrations and more particularly when unmatched tolerance and gaps between mecanichal parts occur.

The so-called "Fretting" corrosion can also be listed.

All those vibrating attacks will not be dealt with in this paper.

2. ENVIRONMENTAL CONDITIONS AND ASSOCIATED CORROSION

2.1 Introduction

Environmental conditions will be broken up into three types :

- climatic : gathering natural elements such as humidity, condensation, thaw, rain, sea air, molds and mildew,
- solvents : all artificial products that can be found in the field,
- electrical : as far as corrosion is concerned this environmental condition is most often combined with the former two i.e. : if a high potential exists between two electrical runs, on a printed wiring board, in a wet atmosphere, an electrolysis could appear and become very significant.

2.2 Tables of environments and corrosion

PHENOMENON	NORMS	TESTING GOALS (Simulated situation)	POSSIBLE ASSOCIATED PROBLEMS	PROBLEMS ENCOUNTERED IN TESTING	OPERATION + ASSOCIATED PROBLEMS
C L I M A T I C S					
HUMIDITY CONDENSATION UNFREEZING	MIL STD 810C + AIR 7304	°Plane parked in a humid climate °Altitude cycles (equipment OFF)	°Degradation of the electrical insulation °Corrosion of the materials in contact with each other by formation of a galvanic couple °If the equipment is switched on : possibility of electrolysis of the materials Hydration of oxydes with the associated loss of conduction	Corrosion of certain mechanical parts	Systems used in marine environments °Corrosion of connectors on some printed circuit boards (attack on the coatings of gold, nickel etc.) °Retention of water in zones near the connectors and electrolysis
ARTIFICIAL RAIN	AIR 7304 THAM 6150	°Handling of equipment outside	°Stagnation of water in the equipment : - short-circuits possible - electrolysis accelerated by the potential difference between connectors - metallic corrosion	°Accumulation of water in certain parts of the equipment and electrolysis accelerated by the potential difference between connectors	
SALT WATER SPRAY	AIR 7304	°Marine climate	°Metallic corrosion °Poor insulation °Deterioration of the electrical contacts	°Corrosion of mechanical parts °Corrosion of connectors	
MOLD AND MILDEW	AIR 7304	°Test done with the mold + mildew found in the countries currently using the system	°Modification of the electrical characteristics °Electrolysis brought on mildew residues °Detachment of the protection coatings and consequently, corrosion underneath	°Degradation of the varnish of some circuit boards (blistering and detachment)	°Poorly stocked equipment (confined area, dark and humid), equatorial and tropical countries °Loss of gold coating and corrosion of components
S O L V E N T S			C O N T A M I N A N T S		
DETERGENTS :		Cleaning of planes (splatters, presence in ventilation)	°Corrosion of mechanical parts °Deterioration of the characteristics of certain products (seals, insulators, etc) and further possible corrosion through deterioration of the protections	NONE	
ALTURET	A				
WD 40	I				These three products are carried together in the ventilation of certain planes. °Detachment or modification of the qualities of varnish, allowing corrosion of the components or connectors
KEROSENE	R	Splatters, presence in ventilation		NONE	
TURBINE OILS		Oil used in the lubrification of reactor disk (splatters, presence in ventilation)			
TH 13 B					
3514	7			Softening of the varnish	
ANTIFREEZE	3	Defrosting of the fuselage and wings		NONE	
Hydraulic Fluid (Skydrol)	0	All hydraulic commands		Paint deterioration varnish deterioration	
Cooling liquids	4	Cooling of equipment		NONE	
Grease AR 4215		Grease used in joints and articulations		NONE	

3. PROBLEMS ASSOCIATED WITH DIFFERENT SYSTEM SECTORS

3.1 External mechanical protections

Proper protection of electronics begins with efficient packaging.

The covers and housings must be conceived to avoid as much penetration of corrosives as possible, while respecting both mechanical and thermal requirements.

Mechanical parts should be designed so as to avoid water accumulation through condensation or defrosting.

Materials used in packaging also have corrosion problems which we will briefly explore here.

MATERIAL UTILIZED (SAGEM AVIONICS)	UTILIZATION	ASSOCIATED CORROSION	PROTECTION USED
ALUMINUM : 5086 (AG4MC)	Basic light parts obtained through processing and not requiring high mechanical performances	Formation of alumina causing poor electrical continuity in the assembly	Chromat layer Nickel-plating Paint
6061	Ditto AG4MC (more rigid parts)	Possible formation of galvanic couples and thus corrosion by loss of substance	"
AlSi 7Mg 03 (AS7G03)	Lost wax casting		"
2017A (AU4G)	Originating from existing shaped parts		Alodine
STEEL X2 Cr Ni 18-10 (Z2 CN 18-10) (Stainless steel)	Small parts	Problems of galvanic couples with other metals (=> attack on the other metals)	Passivation
30 Ni Cr 11 (30 NC 11)	The same usage as stainless steel, however, mechanical resistance is superior with fewer problems of galvanic couples	Corrosion in a marine (salty) environment	Cadmium coating
35 Ni Cr Mo6 (35 NC D 6)			
NEOPRENE RUBBER	O' Ring	Oil, Kerosene, Androx	NONE

NOTES :

- Surface protection for electrical continuity between mechanical parts.

  The surfaces to be connected must be completely free of any oxide or contamination ; it is therefore necessary to apply a specific treatment before any other treatment such as paint or other finish.

  The areas requiring electrical continuity must be masked before applying the second treatment.

- Rubber protection

  Rubber corrosion are not very well known. Corrosion susceptibility depends on the nature of the rubber to be used in a given corrosive atmosphere, rather than on protection of the rubber itself. In all corrosive attacks where oil, kerosene and WD40 are concerned, it is better to use fluorosilicones instead of neoprenes.

3.2 Printed circuit boards, connectors

3.2.1 Materials generally used in our printed circuit boards

SUB-ASSEMBLIES	MATERIALS
Frame	Aluminium (AG5)
Printed circuit	Epoxy (FR4)
Runs	Copper + tin - lead deposit
Contacts	Copper or beryllium copper plated with nickel + gold or just gold
Global protection	Varnish (finish)

3.2.2 Corrosions encountered + probable causes

A) **During operation :**

- Attack of the hybrid case and transistors, cracks developped on the cases. An analysis of the corrosion residues revealed a similar composition to the materials making up the case and its protection (Kovar + gold).

  These attacks were encountered in two different situations :

  1) usage in a marine environment,
  2) usage in a tropical country.

  In both cases, a flaw in the watertightness and quality of the protecting varnish (IB31 MIL-I 46058C) allowed these attacks caused by humidity.

  It should be noted that these hybrid cases are covered with gold and thus protected. This type of attack should therefore not occur.

- Attack of the contacts with degradation of the gold and nickel platings as well as the brass making up the base of the contact.

- Attack of the PCB frame in an area near the contacts mentioned above.

  Probable causes :

  The varnish, attacked in one case by contaminants present in ventilation and in another, by the molds and mildews present in humid tropical air, lost its protective qualities and became porous, thus allowing the action of climatic corroding agents (corrosion of the case).

  Furthermore, presence of areas of humidity and solvent accumulation allowed an electrolysis of the pins, between themselves and with the frame. The pins attacked were of course those supporting the highest voltage.

B) **During qualification tests :**

After an artificial rain test : electrical pins of a small connector were corroded. Associated wire wraps were also degraded and a green foam was found on them.

Probable cause :

water penetrated into the system through an opening located at the base of the system in an area close to the connector, starting an electrolysis when the system was on.

- It should be noted that a highly wet ambiance could trigger the same kind of problem in operation.

3.2.3 Available protection

Each sub-assembly of our electronic modules is protected on an individual basis :

- aluminum frames receive a soft surface protection such as alodine,
- a layer of gold is deposited on copper electrical contacts,
- hybrid cases are made of Kovar plus a layer of gold.

These different protections are not always compatible because of high galvanic couples. They must not be in contact or even too close to each other in the presence of a liquid resulting from condensation or thaw.

To isolate different materials from each other and avoid any humidity or other liquid penetration, the final solution is to coat the entire electronic module with varnish.

In varnishing, however, a new problem arises : it is difficult to inspect if it goes in all interstitial parts and more particularly, between and under component leads and connector pins. The hand made connector located at the base of the module is very sensitive and difficult to coat. One solution applied to some of our systems is to add potting around the connector.

How to evacuate liquid from sensitive areas is another problem. As known, some liquids help electrolytic transfers and often embody corrosives : salt in a marine atmosphere, solvent mixed with cooling air ... When accumulated in the connector area, at the base of the module, they could create corrosion attacks of the varnish and so doing, allow further degradation of the module.

It is therefore vital to eliminate all possible traps for liquids. To create a continuous water drain, associated with good hermeticity of all assembly covers and lids, would be the solution to numerous problems.

Modules with connectors placed along their vertical edges avoid water accumulation problems around them. Unfortunately, it is not always possible to place them so.

Finally, in our systems we must recall that by design the cooling air is forced between the two PWB's and through the frame to get rid of any direct contact between polluted fanned air and an electronic part. Furthermore a hermeticity ribbon all around the PWB's is intented to achieve perfect isolation from the cooling air.

3.2.4 Criteria for the choice of varnish or other protection

Main criteria of choice are :

- resistance to corrosive agents,
- good dismountability for maintenance purposes,
- hygiene : all products used to build, maintain or fix must not be hazardous to the health,
- the ratio cost/service must be evaluated,
- finally the cosmetic aspect may be taken into account. It could be desirable to have a uniform, sleek aspect of the coating with a certain transparency.

We may note that the first two criteria are not always compatible. A corrosive agent resistant coating will quite often be hard to remove when repairing a module, and will necessitate hazardous products for removal.

As often in technical areas, the solution will be a compromise dictated by a budget, of the pros and the cons of the problem to be solved.

3.3 Integrated circuits

Corrosion may be seen inside or outside the case of integrated circuits. External corrosion has already been studied. Internal corrosion is described hereafter.

3.3.1 Corrosion encountered

Electrical bias and humidity are the main activating factors of integrated circuit internal corrosion.

They are responsible for metallic migrations and oxydes being formed which then can produce short or open circuits.

Moisture in the interior atmosphere is quite often due to a lack of hermeticity in package sealing.

Though those phenomena are today well known, they still continue to generate failures in the field.

The types of corrosion most often observed are the metallic ones at the interconnection level :

METALLIZATION	CORROSIVE	CATALYST
Aluminum	chloride (1) phosphorus (2)	water high density
Gold	chloride	water

(1) Cleaning products (2) Si O_2 to isolate

3.3.1.1 Aluminum

Effects of corrosion on *aluminum runs are* open circuits caused by oxydes.

The mechanism is simple : chloride ions make breaches into the natural aluminum passive oxyde skin covering runs and lands. In so doing aluminum comes into direct contact with air moisture and a quick corrosion appears all over the unbiased chip. Under bias conditions, chloride ions move towards anode runs and lands. Consequently a faster corrosion of positively biased aluminum run is seen.

3.3.1.2 Gold

Effects of corrosion on gold metallizations are short circuits. They are mostly created by electroplated gold dentrites bridging close runs or lands. Electrical bias and moisture, here again, are main factors of the corrosion.

3.3.2 Precautions during production process

Precautions to take during production process are quite obvious : chloride and moisture must be avoided. To do so one must absolutely.

- choose hermetically sealed packaging that is ceramic rather than plastic,

- carefully clean and rince before sealing,

- seal under very dry atmosphere and if possible under neutral gas, such as nitrogen.

SiO_2 isolation layers on chips or any other coating can reduce the corrosion susceptibility. All those steps must be applied only during the integrated circuit building process at manufacturers facilities.

Avionic equipment companies buy sealed electronic parts. The enemy, if there is one, is already in the box, and in the field, system failures will be observed over a long period of time. Indeed failure occurence is related to corrosives density, to moisture level and to the lenght of time the system is on.

Systematic burn in of all parts of an electronic system will partially kill potentially bad parts by accelerating the corrosion phenomenons.

We, in the past, suffered such an attack due to a faulty production flow chart at an *integrated circuit manufacturer's*. The flow chart showed the following processing path on metal packages :

------ [SEALING] ----- [CLEAN UP] ----- [DIP TIN] ----- [HERMETICITY TEST] ------

In fact some parts had minute holes or cracks and during clean up, chlorides and water penetrated into the case.

Then the dip tin operation of package leads brought tin over holes and cracks making the case hermetic with corrosives inside it. Hermeticity test was then within specifications. Parts were said good parts : it is the Trojan horse of corrosion.

By interchanging phases "HERMETICITY" and "DIP TIN" the problem was solved.

4. FUTURE TRENDS

Anti-corrosion technics are well known. Yet in spite of this, we observe a great deal of failures in the field owed to corrosion attacks. Maintenance cost is consequently at a soaring level.

Influence of corrosion in maintenance cost is still not clear, if not to say unknown.

To have a good understanding of it, it would be necessary to :

- systematically perform analysis of avionics corrosives,

- systematically perform analyses of their origins and effects,

- systematically perform analyses of failures in the field.

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